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# THIRTIETH ANNUAL REPORT

OF

# THE LOCAL GOVERNMENT BOARD, 1900–01.

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IN CONTINUATION OF THE

RT OF THE MEDICAL OFFICER

For 1900–01.

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PUBLIC HEALTH.

# PAPERS

ON

# LEAD-POISONING AND WATER SUPPLIES,

SUBMITTED BY THE

MEDICAL OFFICER

OF

Gt. Brit.

THE LOCAL GOVERNMENT BOARD.

## REPORT BY Dr. HOUSTON ON MOORLAND WATERS IN REGARD OF THEIR ACTION ON LEAD.

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1903

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# REPORT.

## TO THE RIGHT HONOURABLE WALTER HUME LONG, M.P., PRESIDENT OF THE LOCAL GOVERNMENT BOARD.

SIR,

THE various considerations which the Board had in view in directing comprehensive inquiry into moorland waters in respect of their ability to act upon lead were set out in my interim report on "Lead Poisoning referred to Public Water Supplies derived from Moorland Sources," published in 1895.* I then referred to the results of sundry inquiries made by the Board's Medical Department into prevalence of lead poisoning attributable to water supplies, and particularly to reports by the late Dr. Barry and by the late Mr. T. W. Thompson, appearing in the same volume, which showed that such poisoning was known to have occurred at one or another time among a large population inhabiting various sanitary areas in the north of England, all of which are served by public water supplies of moorland origin. In investigating the causes which produced this dangerous property in a water supply, it had been found that much uncertainty existed with regard to the conditions which increased or diminished the liability of a given moorland water to act on lead pipes, and as to the factors governing the difference between soft moorland waters which are, and others which are not, capable of dissolving lead. Moreover, as I had suggested as long ago as 1887, when dealing with data obtained from Sheffield, the problem of the relationship between the conditions of a gathering ground and the lead dissolving property of its water called for consideration of a number of biological as well as of chemical questions, which it was necessary to study in order to arrive at an understanding of the means best suited in a given instance to prevent the acquisition of lead-dissolving properties by a water.

The inquiry finally decided upon, which it was foreseen would necessarily involve a protracted series of observations, was entrusted to Dr. Houston. By 1894, when Dr. Houston had been continuously engaged in this research for over two years, I was enabled from study of the data available to set out in my interim report a summary of the more important facts obtained, and to state the chief inferences which it was then apparent that the results of his inquiries warranted. At that stage, however, it was necessary to defer publication of the details of the various experiments; it was desired that some should be repeated and extended, and, moreover, an important portion of the task allotted to Dr. Houston, that of surveying moorland gathering grounds in Lancashire and Yorkshire, had hardly been begun. On completion of research in these additional directions, Dr. Houston, in intervals of other work for the Board on which he has been engaged, has classified and reviewed the very large mass of experimental data now available on the subject. Some of the principal conclusions which can be drawn from the completed research are stated by him at the end of this volume (pp. 221–224), and it will be seen that these entirely accord with provisional inferences which it was possible to put forward in 1895.

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* Twenty-third Annual Report of the Local Government Board.—Supplement containing the report of the Medical Officer, Appendix A, No. 13.

The results of laboratory experiments made to determine the varying conditions under which a water may retain or lose its ability to dissolve lead have been printed in the form of tables which, for convenience, will be published in a separate volume. The latter will likewise contain records of experiments with bacteria derived from peat, and will also deal with "erosive ability," a quality of acting upon lead possessed by certain waters which is quite distinct from "plumbo-solvency," or ability to dissolve lead. Erosion of lead may be roughly compared to the rusting of iron; when lead is exposed to water possessing this property its surface disintegrates, and scales of lead, in relatively insoluble form, are separated, leaving a new surface ready for further erosion. This is manifested chiefly in the case of bright lead, and, unlike "plumbo-solvency," the degree in which it is possessed by a water bears no definite relation to the acidity of that water.

It is, however, the power to dissolve the lead of water pipes (whether new or old) which renders a moorland water a potential source of danger to the consumer. Though erosive ablity is a factor not to be neglected, it is relatively of much less importance. The present volume deals almost wholly with questions of plumbo-solvency.* Its first part contains records of the sustained observations, made at the moorland gathering area selected at Burnmoor, of the condition of typical pools and springs, and of mixed water in streams and reservoirs, in regard to chemical composition and ability to dissolve lead. These records establish on a broad basis of observation that the factor essential to the possession by a water of plumbo-solvent properties is acidity, and that the degree of acidity and of corresponding plumbo-solvent ability is determined by the presence of peat on the gathering area and by the conditions under which the drainage of the peat gains access to the supply. This conclusion is not invalidated by observations which seem to show that the ratio between the degree of acidity and the degree of plumbo-solvent ability is not necessarily the same for all peaty waters, and that, within limits, particular waters may have, as it were, their own standards in this respect.

---

* It is convenient to retain this term as signifying ability of a water to dissolve lead, though such compound word may be without sufficient warrant, orthographical or other.

Other important Burnmoor records are those which show that certain spring waters may habitually possess power to neutralise the acid of peaty water. So that, given favourable counterbalancing conditions such as were maintained at Burnmoor during the period of observation, a water of mixed origin, which continuously receives a notable proportion of acid and plumbo-solvent water, may nevertheless itself remain without action upon lead.

The second part records the results obtained when the experience of Burnmoor was applied to the moorland gathering grounds of 23 waterworks in Lancashire and Yorkshire, most of which are large sources of supply under the control of the councils of important boroughs or urban districts. The observations recorded by Dr. Houston as a result of his visits to these several gathering areas deserve careful consideration from those responsible for the purity of the supply derived from these areas. Although Dr. Houston's data regarding these waterworks were obtained a few years back, there is reason to believe that as regards at least some of them the conditions at present obtaining are not materially different from those which he describes. In particular instances where the supply of the waterworks has lately been supplemented from other sources, the gathering areas visited by Dr. Houston continue to contribute to the water service. On the other hand at other waterworks extra precautions against lead poisoning have been adopted since Dr. Houston's visit, and occasionally (as in the case of the Bolton supply) such precautions have been taken at the instance of the Board as a result of knowledge obtained from Dr. Houston's inquiry.

At the date of Dr. Houston's survey, out of 58 reservoirs serving these various gathering grounds, no less than 35 contained acid water possessing in greater or less degree plumbo-solvent properties. In many the sources of acidity could be traced to peaty streams or feeders, a list of which is given on p. 215, which either habitually contribute acid water, or which are liable in time of flood to bring into the supply a considerable volume of water possessing decided action upon lead.

Dr. Houston describes in each instance the after history of the acid water from these reservoirs. In some cases its acidity and plumbo-solvent ability is lost by being mingled with a large volume of neutral or acid-neutralising water derived from other sources. In other instances the process of filtration through sand, with or without the provision of special means of neutralising the water, serves to deprive it of its plumbo-solvent properties. Elsewhere, again, the practice of neutralisation with lime or whiting is regarded as essential, and is adopted as matter of routine. It is fortunately the fact that in one or other of these ways the water supplies in question are habitually deprived of ability to act upon lead. But authorities of waterworks supplied from moorland sources would do well to bear in mind continually the potential risks of a supply consisting wholly or partly of water possessing plumbo-solvent properties. Prevalence of lead poisoning attributable to water supplies has, happily, much diminished of late, but there is danger of this very circumstance leading to neglect of adequate precaution in future. Moreover, it is important to remember that if, owing to temporary omission of precaution, a water supply becomes possessed of plumbo-solvent properties for only a brief period, or if, again, a water habitually exercises only a slight solvent action upon lead, it is likely that the number of cases of lead poisoning occurring at a given time will be small, and that few will come under the notice of any one medical observer. It is easy to understand that in such instances mischief may be caused unknown to the responsible authorities, or that, even if mischief is suspected, the matter may receive insufficient attention through failure to realise that in such circumstances the evidence that the poisoning is attributable to the water must of necessity be incomplete.

Properly considered, there is no difficulty whatever in safeguarding a population supplied wholly or partly from moorland sources from risk of receiving water capable of dissolving lead. It is essential, as Dr. Houston shows, to ascertain in the first instance on each source of supply what are the conditions which afford opportunity of introduction of acid water into the service. It is undesirable to rely wholly on any system of neutralising a water, however well such a system may be designed to guard against accident or negligence. The question which should first be asked is whether specially acid water can be altogether excluded from the supply—for example, by eliminating the drainage of special peaty areas, or by providing "leaping weirs," contrivances which ensure that the first washings from the peat after a period of drought are automatically rejected. It is probable that if action in this sense were taken, the waters of many storage reservoirs would lose the acid and plumbo-solvent properties by which they are at present characterised. Given a water supply habitually acid, or liable to become acid, the process of neutralisation may be effected in various ways which Dr. Houston points out. He indicates that perhaps the most satisfactory method is ordinary sand filtration with the addition of some neutralising material (*e.g.*, a thin coating of lime on the surface of the sand with limestone underneath the sand) to the filter, and the subsequent addition of a trace of sodium carbonate to the neutral filtered water.

Whatever method or methods of precaution be adopted, however, it is of first importance that their efficacy should be frequently ascertained by suitable observations on the gathering areas, at the reservoirs, and at the filters, so as to ensure that the precautions afford adequate safeguard not merely against average or normal conditions, but also against those which are exceptional. Examination from time to time in respect of action on lead of samples of water as delivered to the consumer is also valuable, though this proceeding should be regarded merely as a final check on the system of control. It is necessary to remember in this connection that the same waterworks authority may, habitually or occasionally, supply waters of different origin to different parts of the area which it serves, and that in consequence it is important that samples intended to represent water as supplied to the consumer should be chosen with full knowledge of the system of storage and distribution adopted by the waterworks.

The tests for acidity and for plumbo-solvency which Dr. Houston describes on p. 67 were adopted by him after numerous comparative experiments, and should prove useful in making determinations of the kind here in question.

I have the honour to be,
Sir,
Your obedient servant,
W. H. POWER.

September, 1902.

# PART I.

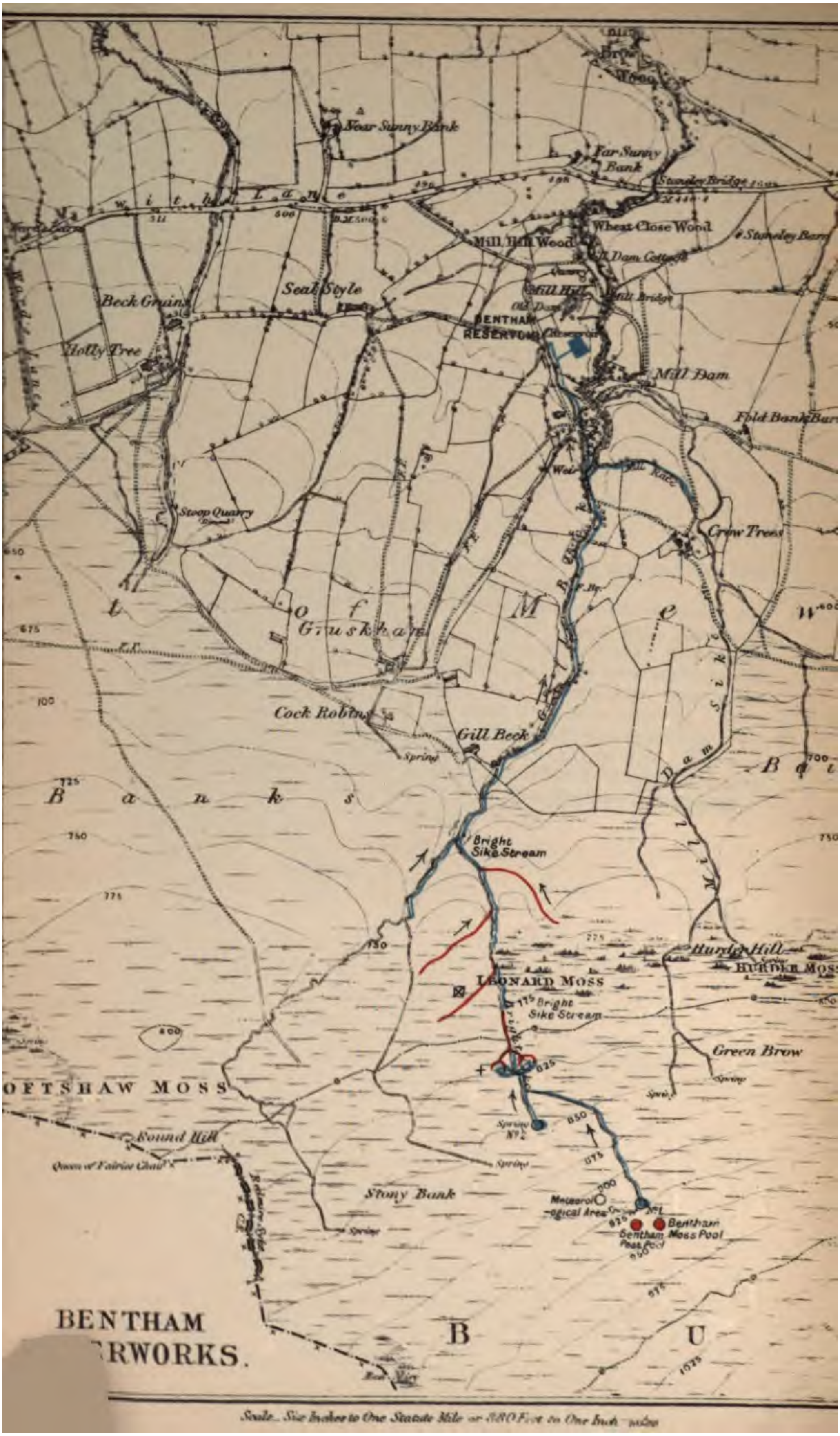
## DIFFERENTIAL EXAMINATION, AT WEEKLY INTERVALS AND OVER A PROLONGED PERIOD, OF WATERS OF DIVERSE SORT FROM ONE AND THE SAME MOORLAND GATHERING GROUND.

### *Bentham Waterworks.*

The red colouring signifies that the water had an acid and the blue colouring a neutral reaction on May 31st, 1895.

On May 31st Bentham Peat and Moss Pools contained hardly any water. It is to be noted that the neutral spring water percolated through the peat at +, and issued again as an acid water which gradually became neutralised in its passage down the rocky and sandy bed of Bright Sike stream. At ⊕ the acid water from a peat drain again changed the reaction of the stream water for a short distance. From this point onward to the reservoir all the water was neutral with the exception of the water from two peat feeders to Bright Sike. The acid water from these feeders was, however, not sufficient in amount to alter the neutral reaction of the stream water. The Bentham Meteorological data were obtained from the point marked ○.

Scale, 6-in. to 1 mile.



**BENTHAM**
**RWORKS.**

*Scale_ Six Inches to One Statute Mile or 880 Feet to One Inch 10560*

## Part I. — Differential examination, at weekly intervals and over a prolonged period, of waters of diverse sort from one and the same moorland gathering ground.

The object of this branch of the inquiry was set out by Mr. Power in the memorandum which appears in the Report of the Medical Officer of the Board for the years 1893–4, and may here be re-stated. It deals with the results of submitting severally to frequent comparative tests waters which, when combined together at a distance from their common *moorland* gathering ground, constitute a public water supply. And this with a view to determine—

(*a*) what are the seasonal modifications of each of such contributory waters;

(*b*) in what way and to what degree they differ at one and another time from each other as regards their constituents;

(*c*) how far diversity of their ability to dissolve lead is associated with season of the year, and is at the same time parallel to observed differences in their chemical and bacterial characters.

A gathering ground of the sort desired was selected at Burnmoor, in the neighbourhood of Settle, in the West Riding of Yorkshire. There was a special advantage in selecting a gathering ground in the West Riding, because this portion of the North of England had for long been associated with a special incidence of lead poisoning due to moorland water supply. On this point the report by the late Dr. Barry to the Board* may be quoted :—

"West Riding of Yorkshire.

"Population obtaining by public service, in the main from moorland sources, water *not filtered* before delivery to consumers, 1,114,077.

"Population obtaining *unfiltered* moorland water to which multiple cases of lead poisoning had in recent years been referred, 677,141."

The selected gathering ground comprised a moorland tract (in every way typical of those larger areas forming Yorkshire gathering grounds) from which water passing over or through the peat, and water also issuing from springs, converged to a particular stream, which in turn supplied a reservoir whence was derived the water supply of Bentham village.

Previous to 1891 this water supply had been credited with the possession from time to time of an extreme degree of acidity, and it was also believed to act on occasion vigorously on lead. As a matter of fact, during the period of investigation by the experts of the Board, the ***sum of the various waters*** constituting the water supply showed little or no evidence of possessing such injurious properties. Nevertheless, certain of the contributory waters were found to be possessed, habitually and in conspicuous degree, of acidity and plumbo-solvent ability, while other contributory waters were found to be either neutral or even alkaline (in the sense of being able to correct acidity), and these had no power of dissolving lead. At Bentham, as elsewhere, the quality of the water supply at any given time must be governed by the inter-reaction of these differing contributory waters, and their relative amounts. And although the sum of the waters at Bentham proved to have no marked lead-dissolving properties during the period under observation, it can readily be understood that this supply is an example of those in which, owing to change in the relative amounts and quality of the constituent waters, a temporary acquisition of lead-dissolving property by the whole water service would be apt to occur.

---

* Records of water supplies in the sanitary districts of Yorkshire, collected as introductory to an investigation by the Medical Department, of the local conditions affecting the solubility of lead by water, by Dr. Barry.

On the Burnmoor gathering ground, it was found that the contributory waters of which I have spoken were of two kinds, and this observation has since been amply confirmed on diverse moorland gathering grounds :—

(*a.*) Acid, peaty water, possessed of plumbo-solvent ability;

(*b.*) Neutral, and often alkaline (in the sense of being able to correct acidity), spring water, devoid of plumbo-solvent ability.

As has been indicated above, the ultimate quality as regards acidity and plumbo-solvent ability of a moorland water supply depends on the inter-reaction of these typical contributory waters (*a*) and (*b*); on the bulk and degree of acidity of the peaty waters (*a*), and the bulk and degree of the acid neutralizing ability of the spring waters (*b*).

This has been repeatedly proved in practice by observation of a moorland stream fed by waters of the characters of (*a*) and (*b*) during dry weather, when the neutral or alkaline spring water (*b*) was relatively at a maximum, and (*a*) at a minimum; and again during floods, when the peaty acid water (*a*) was relatively at a maximum, and spring water (*b*) at a minimum. Under the first set of conditions the moorland stream tends to be neutral and free from action on lead, and under the latter set of conditions tends to be acid and possessed of plumbo-solvent ability. And it is easy, under laboratory conditions of experiment, to show how much of a particular water of the character (*b*) is needed to correct the acidity and plumbo-solvent ability of a water of character (*a*).

With a view to subjecting waters of this type to detailed scrutiny, and to determine the factors which govern the acquisition of plumbo-solvency, the following waters upon the Burnmoor (Bentham) gathering ground were chosen for examination :—

(*a.*) The waters of certain *springs* representing rain which, falling on the gathering ground, had escaped prolonged contact with the peat soil, and had been chemically modified in passage through or between strata underlying the peat. As representative of (*a*) class of waters, two springs were selected, respectively termed in this report—

Bentham (Burnmoor) Spring No. 1
" " " " 2

In the course of the investigation it was ascertained that Spring No. 1 (and in lesser degree Spring No. 2) was subject to occasional contamination with surface peaty water.

(*b.*) The waters of certain *pools* representing rain water that had remained in sustained contact with peat or moss and with living or dead vegetable organic matter. As typical of (*b*) class of waters, two waters were chosen, namely—

Bentham (Burnmoor) Peat Pool
" " Moss Pool

(*c.*) The water of the stream descending towards the service reservoirs, and which represented mixture, differing in proportion from time to time, of waters of the class (*a*) and (*b*). As typical of the (*c*) class of water, a stream was selected, namely,

Bentham (Burnmoor) Bright Syke Stream.

The first survey of this gathering ground was made in 1891. At subsequent dates a further inspection had been made in order to verify the facts previously recorded, to obtain further data, and to prepare the map of the gathering area which faces p. 1.

In order to obtain concurrent data of the physical conditions prevailing during the inquiry, meteorological instruments were established on the gathering ground.

The burden of fitting out the laboratory at Settle in which these experiments were conducted, and of arranging for the collection of samples, controlling and supervising the work, besides personally carrying out much valuable laboratory work, was largely borne by the late Dr. Barry, who in turn was fortunate in securing the active assistance of Dr. Atkinson, Medical Officer of Health for the combined Craven districts, and also of Mrs. Atkinson.

Samples of the selected waters were collected at regular intervals over a long period.

The following is a description of the chemical determinations made in their investigation :—

(*a.*) *Appearance in 2-foot Tube.*—The experiments with the 2-foot tube were carried out in the usual way, and the observations as to colour, turbidity, and residue afforded a rough indication of the quality of the water as regards the presence of suspended and dissolved vegetable matter.

(*b.*) *Reaction with Alcoholic Solutions of Cochineal, Methyl Orange, and Lacmoid.*—These qualitative observations of the reaction of the waters with different and delicate indicators were regarded as important; the reaction of soft moorland waters being not fully understood, there was a presumption in favour of one indicator succeeding where another failed, in demonstrating the presence of acidity, or, it might be, of alkalinity.

(*c.*) *Residue on Evaporation.*—The estimation of the total solids was carried out in the usual manner; and it was considered not unimportant to discover the loss on ignition, as bearing on the different behaviour of vegetable organic matter and mineral matter, when subjected to heat.

(*d.*) *Ammonia (free and albuminoid).*—The ammonia was estimated by Wanklyn's process. Of each sample an amount was distilled sufficient to allow of four lots (each of 50 c.c.) being successively collected and separately Nesslerised *before*, and of other four lots (each of 50 c.c.) being similarly dealt with *after*, the addition of the alkaline permanganate solution. The reason was that experience showed that in many cases, where moorland water was in question, the ammonia was only slowly given off, so that the last 50 c.c. collected contained an appreciable quantity of ammonia. A considerable number of experiments were also carried out to determine the proportion of ammonia attributable to suspended matter ("suspended ammonia") in the several waters examined.

(*e.*) *Oxidised Nitrogen.*—The nitrites were determined qualitatively by Griess's napthylamine process; and the nitrates quantitatively by the copper-zinc couple process.

The determination of the nitrates, and the presence or absence of nitrites, was of importance, as it has been held that the action on lead of waters largely depends on the state of combination of nitrogen with oxygen contained in the water.

(*f.*) *Oxygen required to Oxidize the Organic Matter.*—The oxygen required to oxidize the organic matter was determined by the Tidy process as modified by Blair, the water being kept for two hours at a temperature of 100° C. The standard solutions were sodium thiosulphate and potassium permanganate.

(*g.*) *Chlorine.*—The chlorine was estimated in the usual way, with a standard solution of silver nitrate, and a solution of potassium chromate as indicator.

(*h.*) *Hardness.*—Clarke's soap test was used to determine the hardness.

The importance of keeping a record of the hardness of the waters needs no comment, since many investigators assert that it is especially soft waters which act on lead; that hard waters hardly ever possess this ability.

(*i.*) *Dissolved Oxygen.*—Thresh's process was used to estimate the amount of the dissolved oxygen. The precaution was taken of always having the samples bottles filled completely full of water, and of using—as soon after the collection as possible—the first portion of water taken from the bottle for analysis, for the determination of the dissolved oxygen.

(*j.*) *Iron.*—The presence of iron was always tested for, as a suspicion existed that iron might in some way or other be a factor in giving a water plumbo-solvent ability.

(*k.*) *Acidity.*—Whenever a water was found to give an acid reaction with methyl orange, cochineal, or lacmoid, the amount of the acidity was determined by titrating a known quantity of the water with a decinormal solution of sodic carbonate. Phenolphthalein was used as an indicator, and although open to some objections, it was found that by its use comparable results were obtained. The acidity was estimated quantitatively, with the object of seeing whether the plumbo-solvent ability of a particular water, from time to time, or of one water as compared with another water, varied directly with the amount of the acidity.

(l.) *Plumbo-solvency.*—A determination of the plumbo-solvent properties of the various waters was considered essential; but the difficulty arose that of all the methods in use when this inquiry commenced, none gave comparable results. To Dr. Whitelegge is due the credit of suggesting the filtration of the water through lead shot. It was found, however, that ordinary lead shot did not react very sensibly to the influence of acid waters; shot, therefore, was specially prepared, free from arsenic and the other impurities which give to ordinary lead shot its necessary quality of hardness.

The process was carried out in the following way:—

Fifty c.c. (by volume) of washed lead shot were placed in a burette, occupying 18 inches of its length, and the sample water allowed to filter slowly downwards through the lead. The water was collected in successive lots of 50 c.c. and tested with sulphuretted hydrogen or ammonium sulphide for the presence of lead. The amount of lead was estimated by colour-titration, the standard solution of lead acetate being of such a strength that 1 c.c. was equivalent to 1 mgrm. of lead.

The experiments were carried out in a comparative manner, and the precaution was taken of using fresh shot for each determination, the old shot being thrown aside, lest its use should introduce a possible source of error.

A note was taken of the temperature of the water during the course of the experiment.

*Taking now the several waters seriatim*, the detailed results obtained will first be stated in the five following tables I. to V.:—

### TABLE

### Showing the RECORD of the CHEMICAL EXAMINATION

### Results stated in

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidised Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1–2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1891. Nov. 9 | — | — | — | Neut. | Neut. | — | 6·0 | 2·0 | 4·0 | 0·0026 | 0·0060 | — | — |
| ,, 16 | — | — | — | ,, | ,, | — | 7·0 | 2·5 | 4·5 | 0·0040 | 0·0120 | — | — |
| ,, 23 | — | — | — | ,, | ,, | — | 6·0 | 4·0 | 2·0 | 0·0026 | 0·0060 | — | — |
| ,, 30 | — | — | — | ,, | ,, | Neut. | 6·0 | 3·0 | 3·0 | 0·0080 | 0·0220 | 0·0288 | — |
| Dec. 7 | — | — | — | ,, | ,, | ,, | 11·0 | 5·6 | 5·4 | 0·0170 | 0·0361 | 0·1078 | — |
| ,, 14 | P. straw | Slight | Nil | ,, | ,, | ,, | 13·1 | 5·3 | 7·8 | 0·0060 | 0·0202 | 0·0782 | — |
| ,, 21 | ,, | ,, | ,, | ,, | ,, | ,, | 7·5 | 2·25 | 5·25 | 0·0130 | 0·0240 | 0·0000 | Nil |
| ,, 28 | ,, | ,, | ,, | ,, | ,, | ,, | 7·0 | 4·0 | 3·20 | 0·0120 | 0·0300 | 0·0288 | ,, |
| 1892. Jan. 4 | ,, | ,, | Slight | ,, | ,, | ,, | 5·9 | 1·7 | 4·20 | 0·0096 | 0·0116 | 0·0266 | ,, |
| ,, 11 | ,, | ,, | Moss | ,, | ,, | ,, | 6·5 | 4·0 | 2·50 | 0·0040 | 0·0410 | 0·0906 | Traces |
| ,, 18 | ,, | ,, | Slight | ,, | ,, | ,, | 5·0 | 2·0 | 3·0 | 0·0060 | 0·0185 | 0·0432 | ,, |
| ,, 25 | P. green | ,, | ,, | ,, | ,, | ,, | 7·0 | 3·5 | 3·5 | 0·0080 | 0·0175 | 0·0144 | ,, |
| Feb. 1 | P. straw | ,, | ,, | ,, | ,, | ,, | 12·5 | 7·0 | 5·5 | 0·0055 | 0·0215 | 0·0164 | ,, |
| ,, 8 | ,, | ,, | Moss | ,, | ,, | | 5·0 | 1·8 | 3·2 | 0·0075 | 0·0235 | 0·0654 | Nil |
| ,, 15 | ,, | ,, | Slight | ,, | ,, | ,, | 5·0 | 3·0 | 2·0 | 0·0090 | 0·0541 | 0·0720 | Traces |
| ,, 22 | ,, | ,, | ,, | ,, | ,, | ,, | 7·4 | 4·0 | 3·0 | 0·0060 | 0·0425 | 0·0617 | ,, |
| ,, 29 | ,, | Great | Moss | ,, | ,, | ,, | 7·0 | 2·0 | 5·0 | 0·0040 | 0·0286 | 0·0227 | Nil |
| Mar. 7 | Bluish | Clear | Nil | ,, | ,, | ,, | 6·0 | 1·0 | 5·0 | 0·0065 | 0·0170 | 0·0235 | ,, |
| ,, 14 | Straw | Hazy | ,, | ,, | ,, | ,, | 6·0 | 2·0 | 4·0 | 0·0030 | 0·0134 | 0·0230 | Traces |
| ,, 21 | ,, | ,, | ,, | ,, | ,, | ,, | 7·0 | 3·0 | 4·0 | 0·0054 | 0·0152 | 0·0297 | ,, |
| ,, 28 | ,, | ,, | Slight | Ftly. acid. | ,, | Ftly. acid. | 5·0 | 4·0 | 1·0 | 0·0088 | 0·0330 | 0·0305 | Nil |
| April 4 | Bluish | ,, | ,, | ,, | Sl. acid. | ,, | 3·6 | 2·6 | 1·0 | 0·0652 | 0·0614 | 0·0059 | ,, |
| ,, 11 | ,, | ,, | ,, | ,, | Neut. | ,, | 3·5 | 2·5 | 1·0 | 0·0078 | 0·0310 | 0·0057 | ,, |

II.

### of WATER of BENTHAM SPRING No. 2.

Parts per 100,000.

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. Total. 18. | Hardness. Fixed. 19. | Dissolved Oxygen. 20. | Iron. 21. | Acidity or alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | Temperature of Water during Experiments recorded in Cols. 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | °C |
| 0·1358 | 1·0 | 1·6 | — | — | — | — | — | — | — | — | — | — |
| 0·1298 | 0·9 | 2·9 | — | 0·9146 | — | — | — | — | — | — | — | — |
| 0·0706 | 1·0 | 2·8 | — | 0·8904 | — | — | 0·01 | 0·01 | 0·02 | 0·02 | 0·01 | 11 |
| 0·1570 | 1·0 | 4·0 | — | — | — | — | 0·04 | 0·04 | 0·10 | 0·14 | 0·10 | 17 |
| 0·3560 | 1·0 | 3·1 | — | 0·9278 | — | — | 0·02 | 0·02 | 0·02 | 0·02 | 0·02 | 13 |
| 0·2330 | 0·95 | 2·9 | — | 0·9041 | — | — | 0·04 | 0·04 | 0·04 | 0·05 | 0·05 | 15 |
| 0·1573 | 0·6 | 5·4 | — | 1·1300 | — | — | 0·07 | 0·02 | 0·05 | 0·04 | 0·05 | 14 |
| 0·4730 | 0·5 | 2·7 | — | 0·8885 | — | — | 0·00 | 0·00 | 0·05 | 0·04 | 0·04 | 15 |
| 0·1908 | 0·9 | 3·4 | — | 0·8947 | — | — | 0·10 | 0·03 | 0·03 | 0·05 | 0·05 | 15 |
| 0·2158 | 0·9 | 3·3 | — | 0·8840 | — | — | 0·02 | 0·02 | 0·04 | 0·04 | 0·02 | 15 |
| 0·0836 | 0·9 | 2·3 | — | 0·8284 | Nil | — | 0·00 | 0·00 | 0·04 | 0·05 | 0·05 | 14 |
| 0·1864 | 0·95 | 5·4 | — | 1·0856 | - | — | 0·04 | 0·04 | 0·04 | 0·05 | 0·05 | 13 |
| 0·7004 | 0·75 | 3·5 | — | 1·2280 | - | — | 0·05 | 0·05 | 0·02 | 0·00 | 0·05 | 10 |
| 0·5406 | 0·9 | 2·3 | — | 1·0667 | - | — | 0·04 | 0·04 | 0·04 | 0·04 | 0·02 | 16 |
| 0·5132 | 0·85 | 4·9 | — | 0·9713 | - | — | 0·10 | 0·10 | 0·12 | 0·12 | 0·14 | 16 |
| 0·3344 | 0·9 | 4·0 | — | — | - | — | 0·06 | 0·04 | 0·05 | 0·05 | 0·06 | 14 |
| 0·4048 | 0·9 | 5·0 | — | 0·9138 | - | — | 0·05 | 0·05 | 0·05 | 0·05 | 0·05 | 16 |
| 0·2874 | 0·9 | 2·7 | — | 0·8885 | - | — | 0·05 | 0·02 | 0·03 | 0·02 | 0·02 | 12 |
| 0·3073 | 0·8 | 2·9 | 0·1 | 1·2715 | - | — | 0·00 | 0·00 | 0·01 | 0·01 | 0·00 | 9 |
| 0·2861 | 0·9 | 3·1 | 1·0 | 1·1741 | - | — | 0·04 | 0·05 | 0·05 | 0·05 | 0·04 | 16 |
| 0·1861 | 0·9 | 2·8 | 0·0 | 0·7485 | - | +0·5 | 0·00 | 0·00 | 0·00 | 0·00 | 0·05 | 13 |
| 0·7206 | 1·5 | 4·3 | 2·3 | 0·7836 | - | +0·13 | 0·00 | 0·00 | 0·03 | 0·10 | 0·12 | 16 |
| 0·7282 | 1·1 | 3·8 | 2·4 | 0·7516 | - | +0·07 | 0·05 | 0·02 | 0·02 | 0·03 | 0·05 | 9 |

* The sign + signifies positive acidity, and the sign − negative acidity or alkalinity.

**Table II.—**

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1–2. | Colour. 3. | Turbidity. 4. | Residue. 5. | Cochineal. 6. | Methyl Orange. 7. | Lacmoid. 8. | Total. 9. | Loss on Ignition. 10. | Fixed. 11. | Free. 12. | Albuminoid. 13. | Total. 14. | As Nitrites. 15. |
| 1892.<br>April 18 | Straw | Hazy | Peaty | Ftly. acid. | Sl. acid. | Ftly. acid. | 6·0 | 3·0 | 3·0 | 0·0058 | 0·0463 | 0·0093 | Trace |
| ,, 25 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| May 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| ,, 9 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| ,, 16 | Straw | Clear | Nil | Sl. acid. | Neut. | Sl. acid. | 4·7 | 1·2 | 3·5 | 0·0038 | 0·0128 | 0·0181 | Nil |
| ,, 23 | ,, | ,, | ,, | Neut. | ,, | Neut. | 5·5 | 4·0 | 1·5 | 0·0015 | 0·0191 | 0·0316 | ,, |
| ,, 30 | ,, | ,, | ,, | ,, | ,, | ,, | 5·0 | 4·0 | 1·0 | 0·0044 | 0·0130 | 0·0221 | Trace |
| June 6 | ,, | ,, | ,, | ,, | ,, | ,, | 5·5 | 4·0 | 1·5 | 0·0062 | 0·0072 | 0·0032 | Nil |
| ,, 13 | ,, | ,, | ,, | ,, | ,, | ,, | 4·0 | 2·0 | 2·0 | 0·0110 | 0·0072 | 0·0041 | ,, |
| ,, 20 | ,, | ,, | Slight | ,, | ,, | ,, | 4·0 | 3·0 | 1·0 | 0·0068 | 0·0164 | 0·0238 | Trace |
| ,, 27 | ,, | ,, | ,, | ,, | ,, | ,, | 4·0 | 3·0 | 1·0 | 0·0062 | 0·0108 | 0·0189 | Nil |
| July 4 | ,, | ,, | ,, | ,, | ,, | ,, | 5·0 | 3·0 | 2·0 | 0·0056 | 0·0166 | 0·0354 | ,, |
| ,, 11 | ,, | ,, | ,, | ,, | ,, | ,, | 5·0 | 4·0 | 1·0 | 0·0028 | 0·0448 | 0·0164 | ,, |
| ,, 18 | ,, | ,, | Nil | ,, | ,, | ,, | 5·0 | 4·0 | 1·0 | 0·0042 | 0·0104 | 0·0184 | ,, |
| ,, 25 | ,, | ,, | ,, | ,, | ,, | ,, | 6·0 | 5·0 | 1·0 | 0·0028 | 0·0067 | 0·0238 | ,, |
| Aug. 1 | ,, | Cloudy | ,, | ,, | ,, | ,, | 8·0 | 7·0 | 1·0 | 0·0560 | 0·0992 | 0·0156 | ,, |
| ,, 8 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| ,, 15 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| ,, 22 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| ,, 29 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Sept. 5 | Straw | Clear | Nil | Neut. | Neut. | Neut. | 3·0 | 2·5 | 0·5 | 0·0044 | 0·0088 | 0·0205 | Nil |
| ,, 12 | ,, | ,, | ,, | ,, | ,, | ,, | 4·0 | 3·5 | 0·5 | 0·0032 | 0·0027 | — | ,, |
| ,, 19 | ,, | Hazy | Moss | ,, | ,, | ,, | 0·5 | 0·0 | 0·5 | 0·0052 | 0·0334 | 0·0354 | ,, |
| ,, 26 | ,, | Clear | Nil | ,, | ,, | ,, | 4·0 | 1·0 | 3·0 | 0·0044 | 0·0066 | 0·0387 | Trace |
| Oct. 3 | ,, | ,, | ,, | ,, | ,, | ,, | 3·0 | 2·5 | 0·5 | 0·0060 | 0·0190 | 0·0312 | Nil |

*continued.*

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. | | Dissolved Oxygen. 20. | Iron. 21. | Acidity or alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols. 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. 18. | Fixed. 19. | | | | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | ° C. |
| 1·5940 | 1·0 | 2·8 | 1·8 | 0·9614 | Nil | +0·02 | 0·06 | 0·02 | 0·02 | 0·02 | 0·02 | 11 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 0·1918 | 0·85 | 3·5 | 1·4 | 0·9607 | Nil | +0·04 | 0·00 | 0·00 | 0·02 | 0·04 | 0·04 | 13 |
| 0·2500 | 0·95 | 3·8 | 3·3 | 0·9802 | „ | −0·03 | 0·00 | 0·00 | 0·00 | 0·00 | 0·00 | 16 |
| 0·3702 | 1·10 | 2·5 | 1·5 | 1·1593 | „ | −0·03 | 0·00 | 0·00 | 0·00 | 0·00 | 0·00 | 20 |
| 0·3544 | 0·90 | 1·5 | 0·8 | 1·1042 | „ | −0·005 | 0·00 | 0·00 | 0·00 | 0·00 | 0·00 | 20 |
| 0·2268 | 0·95 | 1·0 | 0·8 | 1·1509 | „ | −0·02 | 0·00 | 0·00 | 0·00 | 0·00 | 0·00 | 13 |
| 0·4688 | 0·6 | 1·2 | 0·9 | 1·0278 | „ | −0·05 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 | 14 |
| 0·2468 | 0·55 | 1·4 | 0·4 | 1·0367 | „ | −0·05 | 0·0 | 0·0 | 0 0 | 0·0 | 0·0 | 17 |
| 0·4756 | 0·9 | 2·6 | 1·7 | 1·3784 | „ | −0·30 | 0·02 | 0·02 | 0·02 | 0·02 | 0·02 | 18 |
| 0·1652 | 0·875 | 1·55 | 1·0 | 1·1647 | „ | −0·30 | 0·0 | 0·02 | 0·02 | 0·02 | 0·05 | 15 |
| 0·2142 | 0·85 | 2·24 | 0·37 | 1·4214 | „ | −0·25 | 0·02 | 0·02 | 0·02 | 0·02 | 0·0 | 17 |
| 0·2550 | 0·7 | 2·24 | 0·7 | 1·3547 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 17 |
| 0·5774 | 0·95 | 2·24 | 2·10 | 0·6616 | „ | −0·075 | 0·02 | 0·02 | 0·02 | 0·02 | 0·02 | 20 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 0·1894 | 0·95 | 2·52 | 2·52 | 1·2004 | Nil | −0·0055 | 0·0 | 0·0 | 0·12 | 0·12 | 0·12 | 16 |
| 0·1774 | 1·0 | 6·03 | 1·82 | 0·9950 | „ | −0·05 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 17 |
| 0·2132 | 1·1 | 4·84 | 2·24 | 0·9902 | „ | −0·05 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 15 |
| 0·3814 | 1·0 | 3·64 | 3·64 | 1·2367 | „ | −0·05 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 18 |
| 0·6940 | 0·95 | 2·10 | 2·10 | 1·1950 | „ | −0·05 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 16 |

* The sign + signifies positive acidity and the sign − negative acidity or alkalinity.

TABLE II.

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidised Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1-2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1892. Oct. 10 | Straw | Clear | Nil. | Neut. | Neut. | Neut. | 7·5 | 7·0 | 0·5 | 0·0014 | 0·0072 | 0·0387 | Trace |
| „ 17 | „ | Hazy | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0050 | 0·0178 | 0·0229 | Nil |
| „ 24 | „ | Clear | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0040 | 0·0242 | 0·0311 | „ |
| „ 31 | „ | Hazy | „ | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0046 | 0·0250 | 0·0477 | Trace |
| Nov. 7 | Colourless | „ | „ | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0032 | 0·0142 | 0·0247 | „ |
| „ 14 | Straw | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0074 | 0·0166 | 0·0362 | „ |
| „ 21 | Grey | Clear | „ | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0042 | 0·0194 | 0·03376 | Nil |
| „ 28 | Straw | „ | „ | „ | „ | „ | 5·0 | 4·0 | 1·0 | 0·0030 | 0·0092 | 0·01317 | Trace |
| Dec. 5 | „ | Hazy | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0032 | 0·0128 | 0·01976 | Nil |
| „ 12 | Colourless | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0021 | 0·0114 | 0·0000 | „ |
| „ 19 | „ | „ | „ | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0308 | 0·0090 | 0·01152 | Trace |
| „ 26 | Straw | „ | „ | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0042 | 0·0144 | 0·01317 | Nil |
| 1893. Jan. 2 | „ | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0028 | 0·0164 | 0·02376 | „ |
| „ 9 | „ | „ | „ | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0026 | 0·0150 | 0·01564 | „ |
| „ 16 | „ | „ | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0044 | 0·0144 | 0·01976 | „ |
| „ 23 | „ | Clear | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0026 | 0·0098 | 0·03047 | „ |
| „ 30 | „ | Hazy | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0044 | 0·0208 | 0·01811 | „ |
| Feb. 6 | „ | „ | Slight | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0042 | 0·0148 | 0·0000 | „ |
| „ 13 | Colourless | Clear | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0044 | 0·0088 | 0·02388 | Trace |
| „ 20 | Straw | Hazy | Slight | „ | „ | „ | 3·0 | 2·5 | 0·5 | 0·0020 | 0·0100 | 0·0000 | Nil |
| „ 27 | Colourless | Clear | — | „ | „ | „ | 7·0 | 6·5 | 0·5 | 0·0040 | 0·0170 | 0·03592 | „ |
| Mar. 6 | „ | „ | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0037 | 0·0142 | 0·01235 | „ |
| „ 13 | „ | „ | — | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0032 | 0·0124 | 0·00164 | „ |
| „ 20 | „ | Hazy | Slight | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·00310 | 0·0064 | 0·00782 | „ |
| „ 27 | „ | Clear | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0032 | 0·0176 | 0·00000 | „ |

***—continued.***

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. | | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols. 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. 18. | Fixed. 19. | | | | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | ° C. |
| 0·2728 | 0·65 | 1·96 | 1·96 | 1·2919 | Nil | −0·05 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·4402 | 0·85 | 2·80 | 2·80 | 1·4566 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 11 |
| 0·2044 | 1·0 | 3·22 | 3·22 | 1·4857 | „ | −0·3 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9 |
| 0·1896 | 1·05 | 2·66 | 2·66 | 1·0109 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·2432 | 0·85 | 4·63 | 2·80 | 1·0855 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 15 |
| 0·2384 | 0·975 | 3·22 | 2·94 | 0·9498 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 17 |
| 0·2008 | 0·95 | 0·32 | 0·32 | 0·971 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9 |
| 0·2252 | 0·95 | 0·52 | 0·43 | 1·039 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9 |
| 0·4878 | 1·05 | 0·39 | 0·39 | 1·078 | „ | −0·175 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 8 |
| 0·2574 | 0·95 | 0·34 | 0·39 | 0·952 | „ | −0·150 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 11 |
| 0·1884 | 0·95 | 0·42 | 0·30 | 1·136 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 15 |
| 0·3872 | 1·05 | 0·64 | 0·50 | 0·864 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 4 |
| 0·0274 | 1·05 | 0·60 | 0·35 | 0·844 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 4 |
| 0·0616 | 1·05 | 0·43 | 0·43 | 1·058 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 4 |
| 0·0814 | 0·8 | 4·35 | 4·35 | 1·0369 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 13 |
| 0·3614 | 1·05 | 4·22 | 4·22 | 1·2269 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 13 |
| 0·1492 | 0·975 | 5·33 | 5·33 | 0·8850 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·0384 | 0·775 | 4·07 | 4·07 | 1·3239 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 22 |
| 0·0136 | 0·85 | 4·35 | 4·35 | 1·0864 | „ | −0·225 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 12 |
| 0·2260 | 0·975 | 4·35 | 4·35 | 0·8625 | „ | −0·20 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·1924 | 1·05 | 4·91 | 2·8 | 1·0864 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·1958 | 1·10 | 5·33 | 5·33 | 1·0009 | Trace | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 13 |
| 0·0590 | 0·95 | 5·61 | 5·61 | 0·9419 | Nil | −0·15 | 0·0 | 0·0 | 0·3 | 0·0 | 0·0 | 16 |
| 0·1924 | 1·05 | 5·61 | 5·61 | 0·9845 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 16 |
| 0·1600 | 0·95 | 5·31 | 5·19 | 0·9915 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 19 |

* The sign + signifies positive acidity, and the sign — negative acidity or alkalinity.

## TABLE

### Showing the Record of the Chemical Examination

Results stated in

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidised Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1–2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1892.<br>Mar. 28 | P. blue | Clear | Nil | Sl. al. | Sl. al. | Sl. al. | 5·0 | 3·0 | 2·0 | 0·0040 | 0·0105 | 0·0379 | Nil |
| April 4 | ,, | Hazy | ,, | Al. | Al. | Al. | 3·4 | 1·7 | 1·7 | 0·0080 | 0·0246 | 0·0103 | ,, |
| ,, 11 | ,, | Clear | V. slight | ,, | ,, | ,, | 5·5 | 4·5 | 1·0 | 0·0042 | 0·0132 | 0·0004 | Sl. trace. |
| ,, 18 | P. straw | Hazy | Slight | Neut. | Neut. | Neut. | 3·5 | 1·5 | 2·0 | 0·0029 | 0·0084 | 0·0296 | Nil |
| ,, 25 | ,, | Clear | V. slight | ,, | ,, | ,, | 7·0 | 3·0 | 4·0 | 0·0012 | 0·0040 | 0·0329 | Trace |
| May 2 | V.P. straw | ,, | ,, | Sl. al. | Sl. al. | Sl. al. | 4·5 | 3·5 | 1·0 | 0·0075 | 0·0102 | 0·0201 | Nil |
| ,, 9 | ,, | ,, | ,, | Neut. | Neut. | Neut. | 2·0 | 1·0 | 1·0 | 0·0060 | 0·0125 | 0·0407 | Sl. trace. |
| ,, 16 | ,, | ,, | None | V. sl. al. | ,, | V. sl. al. | 4·5 | 2·0 | 2·5 | 0·0028 | 0·0134 | 0·0182 | Nil |
| ,, 23 | P. straw | ,, | Nil | Neut. | ,, | Neut. | 7·3 | 6·3 | 1·0 | 0·0031 | 0·0228 | 0·0700 | Trace |
| ,, 30 | V.P. straw | ,, | ,, | ,, | ,, | ,, | 7·0 | 6·0 | 1·0 | 0·0042 | 0·0134 | 0·0123 | Nil |
| June 6 | P. straw | Slightly hazy. | Slight | Sl. al. | Sl. al. | Sl. al. | 5·0 | 3·0 | 2·0 | 0·0062 | 0·0128 | 0·0263 | ,, |
| ,, 13 | ,, | ,, | ,, | Neut. | Neut. | Neut. | 5·0 | 4·0 | 1·0 | 0·0016 | 0·0074 | 0·0107 | Trace |
| ,, 20 | Dk. straw | ,, | ,, | ,, | ,, | ,, | 5·5 | 4·5 | 1·0 | 0·0072 | 0·0184 | 0·0205 | Nil |
| ,, 27 | P. straw | Clear | V. slight | ,, | ,, | ,, | 7·0 | 6·0 | 1·0 | 0·0066 | 0·0148 | 0·0337 | ,, |
| July 4 | ,, | ,, | ,, | ,, | ,, | ,, | 6·0 | 3·0 | 3·0 | 0·0056 | 0·0174 | 0·0543 | ,, |
| ,, 11 | ,, | ,, | ,, | ,, | ,, | ,, | 8·0 | 7·0 | 1·0 | 0·0068 | 0·0160 | 0·0567 | ,, |
| ,, 18 | V.P. straw | ,, | Nil | ,, | ,, | ,, | 5·0 | 4·0 | 1·0 | 0·0046 | 0·0158 | 0·0300 | ,, |
| ,, 25 | P. straw | V. slightly hazy. | ,, | ,, | ,, | ,, | 4·0 | 3·0 | 1·0 | 0·0022 | 0·0076 | 0·0181 | ,, |
| Aug. 1 | Straw | Slightly hazy. | ,, | ,, | ,, | ,, | 5·0 | 3·0 | 2·0 | 0·0020 | 0·0133 | 0·0238 | ,, |
| ,, 8 | P. amber | V. slightly hazy. | ,, | ,, | ,, | ,, | 6·0 | 5·0 | 1·0 | 0·0040 | 0·0170 | 0·0016 | ,, |
| ,, 15 | V.P. straw | Slightly hazy. | ,, | ,, | ,, | ,, | 9·0 | 8·0 | 1·0 | 0·0040 | 0·0144 | 0·0172 | A trace |
| ,, 22 | P. straw | Clear | ,, | ,, | ,, | ,, | 3·0 | 2·0 | 1·0 | 0·0062 | 0·0086 | 0·0461 | Nil |
| ,, 29 | Straw | ,, | ,, | ,, | ,, | ,, | 7·0 | 6·0 | 1·0 | 0·0030 | 0·0062 | 0·0119 | ,, |

## III.

## of Water of Bright Syke Stream.

Parts per 100,000.

| Oxygen absorbed from Permanganate at 100° C. 16 | Chlorine. 17. | Hardness. |  | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. |  |  |  |  | Temperature of Water during Experiments recorded in Cols. 23–27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Total. 18. | Fixed. 19. |  |  |  | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | ° C. |
| 0·0586 | 1·00 | 1·0 | 0·0 | 1·1225 | Nil | −0·4 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 12 |
| 0·3444 | 1·10 | 3·1 | 2·2 | 1·1035 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·02 | 0·02 | 16 |
| 0·5656 | 1·025 | 2·6 | 2·0 | 1·0750 | „ | −0·5 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9 |
| 0·2558 | 1·05 | 2·9 | 1·3 | 1·0976 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 11 |
| 0·1548 | 0·95 | 2·6 | 1·9 | 1·2465 | „ | −0·4 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 12 |
| 0·1564 | 1·00 | 2·1 | 1·0 | 1·0974 | „ | −0·3 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 10 |
| 0·1692 | 0·90 | 1·9 | 1·7 | 1·0662 | „ | −0·1 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 12 |
| 0·2928 | 1·05 | 2·4 | 1·3 | 1·1328 | „ | −0·1 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·2520 | 1·05 | 3·1 | 1·7 | 1·1310 | „ | −0·35 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 16 |
| 0·3554 | 1·10 | 2·1 | 1·2 | 0·9602 | „ | −0·3 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 20 |
| 0·2696 | 1·00 | 2·0 | 0·5 | 1·0848 | „ | −0·35 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·2902 | 0·95 | 1·0 | 0·6 | 1·2179 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 0·7640 | 0·90 | 1·45 | 0·8 | 1·1892 | „ | −0·15 | 0·10 | 0·12 | 0·12 | 0·12 | 0·12 | 14 |
| 0·2966 | 0·70 | 1·05 | 0·4 | 1·1222 | „ | −0·20 | 0·04 | 0·04 | 0·04 | 0·04 | 0·04 | 17 |
| 0·5412 | 0·90 | 2·4 | 0·8 | 1·3784 | „ | −0·30 | 0·02 | 0·02 | 0·02 | 0·02 | 0·02 | 18 |
| 0·4116 | 1·00 | 2·5 | 2·4 | 1·1960 | „ | −0·05 | 0·02 | 0·02 | 0·02 | 0·02 | 0·02 | 15 |
| 0·3316 | 1·00 | 1·54 | 1·54 | 0·9197 | „ | −0·45 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 18 |
| 0·2724 | 1·10 | 2·66 | 2·66 | 1·1931 | „ | −0·35 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 17 |
| 0·3524 | 0·70 | 2·55 | 2·55 | 1·2464 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 19 |
| 0·3468 | 0·95 | 3·50 | 3·50 | 1·3966 | „ | −0·1 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 18 |
| 0·3668 | 0·95 | 3·42 | 2·12 | 1·1738 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 16 |
| 0·3380 | 0·95 | 2·12 | 1·26 | 1·1738 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 19 |
| 0·3804 | 0·85 | 2·10 | 2·10 | 1·2900 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 17 |

† The sign + signifies positive acidity, and the sign — negative acidity or al

**TABLE**

| ate of ollection and of xamination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-2. | Colour. 3. | Turbidity. 4. | Residue. 5 | Cochineal. 6. | Methyl Orange. 7. | Lacmoid. 8. | Total. 9. | Loss on Ignition. 10. | Fixed. 11. | Free. 12. | Albuminoid. 13. | Total. 14. | As Nitrites. 15. |
| 1892. pt. 5 | Straw | Clear | Nil | Neut. | Neut. | Neut. | 6·5 | 6·0 | 0·5 | 0·0046 | 0·0104 | 0·0634 | Nil |
| „ 12 | Yellow | „ | „ | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0122 | 0·0130 | 0·0329 | Present |
| „ 19 | P. straw | „ | „ | „ | „ | „ | 5·5 | 5·2 | 0·3 | 0·0052 | 0·0280 | 0·1070 | A trace |
| „ 26 | Straw | „ | „ | „ | „ | „ | 4·0 | 3·0 | 1·0 | 0·0032 | 0·0196 | 0·0329 | Nil |
| t. 3 | | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0048 | 0·0222 | 0·0321 | „ |
| „ 10 | „ | „ | „ | „ | „ | „ | 3·5 | 1·0 | 2·5 | 0·0026 | 0·0132 | 0·0411 | „ |
| „ 17 | „ | V.slightly hazy. | „ | „ | „ | „ | 10·0 | 6·0 | 4·0 | 0·0036 | 0·0182 | 0·0237 | „ |
| „ 24 | V.P. straw | Clear | „ | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0068 | 0·0182 | 0·0485 | A trace |
| „ 31 | Straw | V.slightly hazy. | „ | „ | „ | „ | 3·5 | 3·0 | 0·5 | 0·0038 | 0·0258 | 0·0451 | „ |
| ov. 7 | P. straw | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0034 | 0·0142 | 0·0312 | „ |
| „ 14 | Straw | Hazy | Slight | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0058 | 0·0136 | 0·0592 | „ |
| „ 21 | P. straw | V. S. hazy | None | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0048 | 0·0126 | 0·01729 | A trace |
| „ 28 | Straw | Clear | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0038 | 0·0136 | 0·03211 | Present |
| ec. 5 | „ | S. hazy | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0038 | 0·0104 | 0·02552 | Nil |
| „ 12 | V. P. straw | V. S. hazy | „ | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0018 | 0·0252 | 0·00000 | Considerable |
| „ 19 | Straw | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0240 | 0·0294 | 0·00000 | Nil |
| „ 26 | V. P. straw | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0038 | 0·0092 | 0·01317 | S. trace |
| 1893. Jan. 2 | „ | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0030 | 0·0086 | 0·03088 | Nil |
| „ 9 | „ | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0022 | 0·0074 | 0·01564 | „ |
| „ 16 | „ | „ | — | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0040 | 0·0080 | 0·01976 | „ |
| „ 23 | P. straw | „ | — | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0038 | 0·0140 | 0·05105 | A trace |
| „ 30 | „ | S. hazy | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0044 | 0·0220 | 0·01400 | Nil |
| Feb. 6 | V. P. straw | V. S. hazy | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0048 | 0·0086 | 0·00000 | „ |
| „ 13 | P. Straw | Clear | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0050 | 0·0164 | 0·03128 | „ |
| „ 20 | Straw | „ | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0056 | 0·0176 | 0·04940 | „ |

*inued.*

| gen bed m an- te at ° C. |  | Hardness. |  | Dissolved Oxygen. | Iron. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* | Plumbo-solvency as shown by Amount of Lead taken up in Samples. |  |  |  |  | Temperature of Water during Experiments recorded in Cols. 23–27. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Chlorine. | Total. | Fixed. |  |  |  | A. | B. | C. | D. | E. |  |
| . | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. |
|  |  |  |  |  |  |  |  |  |  |  |  | ° C. |
| 98 | 1·05 | 2·52 | 2·52 | 1·2804 | Nil | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 16 |
| 58 | 0·90 | 3·08 | 2·52 | 1·2179 | „ | −0·10 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 18 |
| 92 | 1·10 | 3·71 | 3·22 | 1·2034 | „ | −0·10 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 16 |
| 96 | 1·05 | 4·07 | 4·07 | 1·1931 | „ | −0·5 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 18 |
| 96 | 0·95 | 2·38 | 2·10 | 1·2435 | „ | −0·1 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 15 |
| 94 | 1·15 | 2·52 | 2·52 | 1·3016 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 24 | 0·80 | 4·35 | 3·64 | 1·4469 | „ | −0·45 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 11 |
| 38 | 1·00 | 3·22 | 3·22 | 1·3694 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 8 |
| 02 | 1·00 | 3·64 | 3·36 | 1·1272 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 80 | 0·90 | 3·85 | 3·15 | 1·4440 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 42 | 1·00 | 3·08 | 3·08 | 1·3471 | „ | −0·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 17 |
| 44 | 1·00 | 3·3 | 2·5 | 1·495 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9 |
| 48 | 1·00 | 4·6 | 4·6 | 1·340 | „ | −0·20 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 10 |
| 74 | 0·85 | 3·5 | 3·5 | 1·281 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9 |
| 24 | 1·05 | 5·3 | 5·3 | 1·349 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 11 |
| 06 | 0·95 | 2·6 | 2·6 | 1·194 | „ | −0·15 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 15 |
| 30 | 1·15 | 5·0 | 5·0 | 1·397 | „ | −0·30 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 4 |
| 32 | 0·95 | 3·5 | 3·5 | 1·416 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 4 |
| 4 | 1·00 | 3·5 | 3·5 | 1·251 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 4 |
| 0 | 0·70 | 2·80 | 2·80 | 1·0369 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 13 |
| 6 | 1·05 | 3·22 | 6·31 | 1·3404 | „ | −0·25 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 13 |
| 8 | 1·00 | 5·61 | 5·61 | 1·2553 | „ | −0·20 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |
| 8 | 0·925 | 3·50 | 4·49 | 1·3423 | „ | −0·275 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 22 |
| 8 | 1·00 | 3·50 | 3·50 | 1·2573 | „ | −0·20 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 12 |
| 8 | 0·950 | 3·50 | 5·61 | 1·2183 | „ | −0·20 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 14 |

* The sign + signifies positive acidity, and the sign — negative acidity or alka

**TABLE III.-**

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1–2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1893. Feb. 27 | V. P. straw | Clear | — | Neut. | Neut. | Neut. | 5·0 | 4·5 | 0·5 | 0·0014 | 0·0100 | 0·03047 | A trac |
| Mar. 6 | P. straw | V. S. hazy | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0028 | 0·0126 | 0·02600 | Nil |
| „ 13 | V. P. straw | „ | — | „ | „ | „ | 3·5 | 3·0 | 0·5 | 0·0028 | 0·0104 | 0·01647 | „ |
| „ 20 | Strawtinge | „ | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0026 | 0·0090 | 0·02228 | „ |
| „ 27 | V. P. straw | „ | — | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0054 | 0·0096 | 0·0000 | „ |

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**TABL**

**Showing the RECORD of the CHEMICAL EXAMINATIO**

**Results stated i**

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1–2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1891. Nov. 9 | — | — | — | Acid | Acid | — | — | — | — | 0·0052 | 0·0590 | — | — |
| „ 16 | — | — | — | „ | „ | — | — | — | — | 0·0013 | 0·0380 | — | — |
| „ 23 | — | — | — | „ | „ | — | 8·0 | 6·0 | 2·0 | 0·0013 | 0·0440 | — | — |
| „ 30 | — | — | — | „ | „ | Acid | 15·0 | 13·0 | 2·0 | 0·0013 | 0·0380 | 0·0123 | — |
| Dec. 7 | — | — | — | „ | „ | „ | 6·0 | 4·5 | 1·5 | 0·0157 | 0·0398 | 0·0246 | — |
| „ 14 | Amber | Clear | Slight | „ | „ | „ | 5·8 | 3·8 | 2·0 | 0·0070 | 0·0268 | 0·000 | Nil |
| „ 21 | „ | Much | Peaty | „ | „ | „ | 9·5 | 6·2 | 3·3 | 0·0045 | 0·1060 | 0·0148 | „ |
| „ 28 | „ | Clear | Slight | „ | „ | „ | 9·0 | 6·0 | 3·0 | 0·0100 | 0·0510 | 0·0082 | „ |
| 1892. Jan. 4 | Brown | Much | Peaty | Neut. | Neut. | Neut. | 9·5 | 6·5 | 3·0 | 0·0098 | 0·2744 | 0·0700 | „ |
| „ 11 | Amber | Slight | „ | Acid | Acid | „ | 14·8 | 9·5 | 5·3 | 0·0220 | 0·2170 | 0·2595 | „ |
| „ 18 | — | — | — | — | — | — | — | — | — | — | — | — | — |

*ued.*

| ren<br>bed<br>m<br>ıan-<br>te at<br>° C. | Chlorine. | Hardness. |  | Dissolved Oxygen. | Iron. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* | Plumbo-solvency as shown by Amount of Lead taken up in Samples. |  |  |  |  | Temperature of Water during Experiments recorded in Cols. 23–27. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Total. | Fixed. |  |  |  | A. | B. | C. | D. | E. |  |
| 5. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. |
|  |  |  |  |  |  |  |  |  |  |  |  | ° C. |
| 50 | 1·05 | 5·33 | 4·91 | 1·[illegible] | A trace | —4·[illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | 0·95 | 1·96 | 6·31 | 1·2254 | Nil | —4·[illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | 1·05 | 2·10 | 3·50 | 1·[illegible] | „ | —4·15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | 1·05 | 4·07 | 4·63 | 1·2364 | „ | —4·35 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 00 | 1·00 | 4·91 | 3·64 | 1·2822 | „ | —4·25 | [illegible] | [illegible] | [illegible] | 4·1 | [illegible] | [illegible] |

## he WATER of BENTHAM PEAT POOL.

ts per 100,000.

| gen<br>bed<br>m<br>ıan-<br>e at<br>C. | Chlorine. | Hardness. |  | Dissolved Oxygen. | Iron. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* | Plumbo-solvency as shown by Amount of Lead taken up in Samples. |  |  |  |  | Temperature of Water during Experiments recorded in Cols. 23–27. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Total. | Fixed. |  |  |  | A. | B. | C. | D. | E. |  |
|  | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. |
|  |  |  |  |  |  |  |  |  |  |  |  | ° C. |
|  | 1·00 | 1·5 | — | 0·9429 | — | — | — | — | — | — | — | — |
| 03 | 1·10 | — | — | 0·8229 | — | — | — | — | — | — | — | — |
| 88 | 1·10 | 2·7 | — | — | — | — | 1·[illegible] | 1·[illegible] | 1·[illegible] | 1·74 | 1·[illegible] | [illegible] |
| 22 | 1·00 | 4·0 | — | 0·9467 | — | — | 1·[illegible] | 1·[illegible] | 1·[illegible] | 1·[illegible] | 1·[illegible] | [illegible] |
| 10 | 0·50 | 0·2 | — | 1·0083 | — | — | 1·[illegible] | 1·[illegible] | 1·72 | 1·22 | 1·[illegible] | [illegible] |
| 26 | 1·00 | 0·7 | — | 0·8826 | — | — | 0·[illegible] | 0·[illegible] | 1·[illegible] | 1·72 | 1·[illegible] | [illegible] |
| 72 | 0·90 | 2·5 | — | 1·2642 | — | — | 1·[illegible] | 1·45 | 1·46 | 1·46 | 1·22 | [illegible] |
| 14 | 0·80 | 1·2 | — | 1·0829 | — | — | 1·[illegible] | 1·14 | 1·[illegible] | 1·[illegible] | 1·[illegible] | [illegible] |
| 02 | 0·90 | 0·8 | — | 0·9328 | — | — | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 06 | 0·20 | 2·2 | — | — | — | — | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|  | — | — | — | — | — | — | — | — | — | — |  | — |

* The sign + signifies positive acidity, and the sign — negative acidity or alkalinity.

x. 2

TABLE IV.

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1-2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1892. Jan. 25 | Amber | Slight | Slight | Acid | Acid | Acid | 6·0 | 5·0 | 1·0 | 0·0040 | 0·0240 | 0·0082 | Trace |
| Feb. 1 | „ | Much | Peaty | „ | „ | „ | 9·0 | 7·5 | 1·5 | 0·0042 | 0·0360 | 0·000 | Nil |
| „ 8 | „ | Clear | Slight | „ | „ | „ | 7·0 | 6·0 | 1·0 | 0·0065 | 0·0290 | 0·0539 | Trace |
| „ 15 | „ | Hazy | Muddy | „ | „ | „ | 6·0 | 5·0 | 1·0 | 0·0075 | 0·0590 | 0·0559 | Nil |
| „ 22 | Straw | „ | Slight | Neut. | Neut. | Neut. | 11·5 | 8·5 | 3·0 | 0·0440 | 0·0980 | 0·0638 | „ |
| „ 29 | Amber | Much | Peaty | „ | „ | „ | 11·0 | 7·0 | 4·0 | 0·0116 | 0·0324 | 0·0181 | „ |
| Mar. 7 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 14 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 21 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 28 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Apr. 4 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 11 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 18 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 25 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| May 2 | Amber | Cloudy | Peaty | Acid | Acid | Acid | 16·5 | 10·5 | 6·0 | 0·0084 | 0·2332 | 0·0169 | Nil |
| „ 9 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 16 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 23 | Yellow | Cloudy | Slight | Acid | Acid | Acid | 11·0 | 9·0 | 2·0 | 0·0017 | 0·0990 | 0·1200 | Nil |
| „ 30 | Straw | „ | „ | Neut. | Neut. | Neut. | — | — | — | 0·0034 | 0·0374 | 0·0436 | „ |
| June 6 | Amber | Hazy | „ | Acid | Acid | Acid | 5·0 | 4·0 | 1·0 | 0·0072 | 0·0848 | 0·2168 | „ |
| „ 13 | „ | „ | „ | „ | „ | „ | 8·0 | 7·0 | 1·0 | 0·0098 | 0·0818 | 0·0098 | „ |
| „ 20 | „ | Cloudy | Muddy | „ | „ | „ | 5·0 | 4·0 | 1·0 | 0·0032 | 0·0776 | 0·0321 | Trace |
| „ 27 | „ | Hazy | Slight | „ | „ | „ | 10·0 | 9·0 | 1·0 | 0·0044 | 0·0700 | 0·0346 | Nil |
| July 4 | „ | Cloudy | „ | „ | „ | „ | 12·0 | 10·0 | 2·0 | 0·0040 | 0·0788 | 0·0458 | „ |
| „ 11 | „ | „ | „ | „ | „ | „ | 5·0 | 4·0 | ·0 | 0·0018 | 0·1120 | 0·0354 | „ |

***ontinued.***

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. Total. 18. | Hardness. Fixed. 19. | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required t neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | Temperature of Water during Experiments recorded in Cols. 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | ° C. |
| 1·8514 | 0·90 | 1·3 | — | 1·2181 | Nil | — | 0·60 | 0·76 | 0·70 | 0·74 | 0·72 | 17 |
| 1·7460 | 0·80 | 1·9 | — | 1·1975 | " | — | 0·60 | 0·74 | 0·74 | 0·66 | 0·70 | 16 |
| 2·0190 | 1·40 | 1·2 | — | 1·2171 | " | — | 0·70 | 0·76 | 0·76 | 0·76 | 0·80 | 16 |
| 2·9188 | 0·80 | 2·0 | — | 1·2555 | " | — | 0·72 | 1·02 | 1·02 | 1·12 | 1·42 | 14 |
| 1·8544 | 0·90 | 1·2 | — | — | " | — | 0·14 | 0·16 | 0·16 | 0·16 | 0·16 | 17 |
| 3·0936 | 0·85 | 2·6 | — | — | " | — | 0·16 | 0·16 | 0·16 | 0·16 | 0·16 | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 2·7540 | 1·70 | 5·3 | 3·5 | — | Nil | +0·40 | 1·00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | |
| 1·3124 | 1·00 | 3·4 | 2·5 | 0·8085 | Trace | +0·65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1·2696 | 1·00 | — | — | 0·8457 | Nil | −0·05 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1·9633 | 1·10 | 1·5 | — | 0·7242 | " | +0·13 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1·9560 | 1·10 | 2·0 | — | 1·0968 | Trace | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1·5696 | 0·80 | 1·3 | — | 1·0849 | Nil | +0·05 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1·5950 | 0·90 | 2·5 | — | 0·7137 | Trace | +0·15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2·5120 | 1·20 | 3·05 | 1·7 | 0·9132 | Trace | −0·15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2·3474 | 1·25 | 2·6 | 1·35 | 0·9617 | Nil | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

* The sign + signifies positive acidity, and the sign − negative acidity or alkalinity.

### TABLE IV.–

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1–2. | Colour. 3. | Turbidity. 4. | Residue. 5. | Cochineal. 6. | Methyl Orange. 7. | Lacmoid. 8. | Total. 9. | Loss on Ignition. 10. | Fixed. 11. | Free. 12 | Albuminoid. 13. | Total. 14. | As Nitrites. 15. |
| 1892.<br>July 18 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 25 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Aug. 1 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 8 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 15 | Amber | Hazy | Slight | Acid | Acid | Acid | 10·0 | 9·0 | 1·0 | 0·0032 | 0·0948 | 0·0551 | Nil |
| „ 22 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 29 | Amber | Clear | Nil | Acid | Acid | Acid | 10·0 | 9·0 | 1·0 | 0·0028 | 0·0366 | 0·0350 | Nil |
| Sept. 5 | „ | „ | „ | „ | „ | „ | 3·0 | 2·5 | 0·5 | 0·0030 | 0·0230 | 0·0148 | „ |
| „ 12 | „ | „ | „ | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0020 | 0·0424 | 0·0065 | „ |
| „ 19 | „ | Hazy | Slight | „ | „ | „ | 5·0 | 4·9 | 0·1 | 0·0008 | 0·0510 | 0·0187 | „ |
| „ 26 | Sherry | Clear | Nil | „ | „ | „ | 9·0 | 8·5 | 0·5 | 0·0028 | 0·0654 | 0·0271 | „ |
| Oct. 3 | Amber | Hazy | Slight | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0034 | 0·0390 | 0·0107 | „ |
| „ 10 | „ | Clear | Nil | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0020 | 0·0426 | 0·0057 | „ |
| „ 17 | Sherry | „ | Slight | „ | „ | „ | 8·0 | 7·5 | 0·5 | 0·0032 | 0·0472 | 0·0189 | „ |
| „ 24 | Amber | Hazy | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0032 | 0·0560 | 0·0461 | „ |
| „ 31 | „ | Clear | Nil | „ | „ | „ | 2·5 | 2·0 | 0·5 | 0·0034 | 0·0318 | 0·0189 | „ |
| Nov. 7 | „ | Hazy | Slight | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0020 | 0·0560 | 0·0197 | „ |
| „ 14 | „ | Clear | Nil | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0016 | 0·0278 | 0·0288 | A trace |
| „ 21 | „ | Hazy | None | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0032 | 0·0340 | 0·00741 | None |
| „ 28 | „ | Clear | „ | „ | „ | „ | 3·5 | 3·0 | 0·5 | 0·0010 | 0·0206 | 0·00494 | Nil |
| Dec. 5 | „ | Hazy | Slight | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0022 | 0·0296 | 0·03129 | „ |
| „ 12 | Straw | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0010 | 0·0268 | 0·0000 | „ |
| „ 19 | — | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0080 | 0·0226 | 0·00164 | „ |
| „ 26 | Amber | Cloudy | „ | „ | „ | „ | 7·0 | 6·9 | 0·1 | 0·0028 | 0·1460 | 0·03541 | „ |
| 1893.<br>Jan. 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |

*Continued.*

| Oxygen absorbed from Permanganate at 100° C. | Chlorine. | Hardness. | | Dissolved Oxygen. | Iron. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols. 23–27. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. | Fixed. | | | | A. | B. | C. | D. | E. | |
| 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. |
| | | | | | | | | | | | | ° C. |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1·3844 | 1·10 | 5·33 | 1·54 | 0·8734 | Trace | +0·2 | 1·60 | ·60 | 1 60 | 1·60 | 1·60 | 17 |
| — | — | — | — | — | — | — | — | | | — | — | — |
| 1·7222 | 0·95 | 5·19 | 4·21 | 1·0575 | Present | +1·35 | 1·20 | 1 20 | ·20 | 1 20 | 1·20 | 17 |
| 1·6648 | 0·80 | 2·17 | 1·61 | 1·1738 | Nil | +0·7 | 1·40 | 1·60 | ·60 | 1·60 | 1·60 | 15 |
| 1·8224 | 1·05 | 2·80 | 1·68 | 1·1743 | Trace | +0·8 | 1·30 | 1·30 | 1·30 | ·30 | 1·30 | 18 |
| 1·7972 | 0·90 | 3·22 | 1·40 | 0·9514 | „ | +1·1 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 16 |
| 3·8658 | 1·10 | 3·36 | 2·24 | 0·8901 | „ | +1·4 | 2·20 | 2·20 | 2·20 | 2·20 | ·20 | 17 |
| 2·0814 | 0·95 | 2·10 | 2·10 | 1·0787 | „ | +0·8 | 1·40 | 1·40 | 1·40 | ·40 | ·40 | 14 |
| 2·5918 | 0·95 | 1 54 | 1·54 | 1·3404 | Nil | +0·6 | 0·80 | 0·80 | 0·80 | 0·80 | 0·80 | 13 |
| 2·9004 | 1·15 | 2·80 | 2·80 | 1·4179 | „ | +1·25 | 2·40 | 2·40 | 2·40 | 2·40 | 2·40 | 11 |
| 1·4740 | 1·00 | 2·10 | 2·10 | 1·0884 | Trace | +0·7 | 1·20 | ·20 | 1·20 | 1·20 | ·20 | 8 |
| 2·3714 | 0·90 | 2·10 | 2·10 | 1·3016 | Nil | +0·7 | 1·30 | ·30 | 1·30 | ·30 | ·30 | 13 |
| 1·3506 | 0·85 | 3·64 | 3·64 | 1·2699 | Trace | +1·5 | 2·00 | ·40 | 2·40 | 2·80 | 2·80 | 14 |
| 0·8564 | 0·85 | 2·10 | 2·10 | 1·2018 | „ | +0·6 | 1·80 | 1·80 | 1·80 | ·80 | 1·80 | 17 |
| 1·2254 | 0·80 | 3·9 | 3·9 | 1·233 | Traces | +0·85 | 1·80 | 1·80 | 1·80 | ·80 | 1 80 | 9 |
| 0·8402 | 0·925 | 8·2 | 5·5 | 1·039 | Trace | +0·8 | 1·80 | 1·80 | 1·80 | ·80 | 1·80 | 10 |
| 1·0828 | 0·90 | 3·5 | 2·8 | 1·036 | „ | +0·65 | 1·60 | 1·60 | 1 60 | ·60 | 1 60 | 9 |
| 1·0600 | 0·95 | 3·3 | 3·3 | 1·262 | „ | +0·45 | 0·90 | 0·90 | 0·90 | 0·90 | 0·90 | 11 |
| 1·1432 | 0·80 | 2·3 | 2·3 | 1·223 | „ | +0·45 | 1·00 | 1·00 | 1·00 | 1·00 | ·00 | 14 |
| 1·5820 | 1·30 | 6·4 | 6·4 | 1·029 | Abundant. | +2·4 | 1·40 | 1·40 | 1·40 | 1·40 | 1·40 | 4 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |

* The sign + signifies positive acidity, and the sign — negative acidity or alkalinity.

TABLE IV.

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1–2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1892. July 18 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 25 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Aug. 1 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 8 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 15 | Amber | Hazy | Slight | Acid | Acid | Acid | 10·0 | 9·0 | 1·0 | 0·0032 | 0·0948 | 0·0551 | Nil |
| „ 22 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 29 | Amber | Clear | Nil | Acid | Acid | Acid | 10·0 | 9·0 | 1·0 | 0·0028 | 0·0366 | 0·0350 | Nil |
| Sept. 5 | „ | „ | „ | „ | „ | „ | 3·0 | 2·5 | 0·5 | 0·0030 | 0·0230 | 0·0148 | „ |
| „ 12 | „ | „ | „ | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0020 | 0·0424 | 0·0065 | „ |
| „ 19 | „ | Hazy | Slight | „ | „ | „ | 5·0 | 4·9 | 0·1 | 0·0008 | 0·0510 | 0·0187 | „ |
| „ 26 | Sherry | Clear | Nil | „ | „ | „ | 9·0 | 8·5 | 0·5 | 0·0028 | 0·0654 | 0·0271 | „ |
| Oct. 3 | Amber | Hazy | Slight | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0034 | 0·0390 | 0·0107 | „ |
| „ 10 | „ | Clear | Nil | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0020 | 0·0426 | 0·0057 | „ |
| „ 17 | Sherry | „ | Slight | „ | „ | „ | 8·0 | 7·5 | 0·5 | 0·0032 | 0·0472 | 0·0189 | „ |
| „ 24 | Amber | Hazy | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0032 | 0·0560 | 0·0461 | „ |
| „ 31 | „ | Clear | Nil | „ | „ | „ | 2·5 | 2·0 | 0·5 | 0·0034 | 0·0318 | 0·0189 | „ |
| Nov. 7 | „ | Hazy | Slight | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0020 | 0·0560 | 0·0197 | „ |
| „ 14 | „ | Clear | Nil | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0016 | 0·0278 | 0·0288 | A trace |
| „ 21 | „ | Hazy | None | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0032 | 0·0340 | 0·00741 | None |
| „ 28 | „ | Clear | „ | „ | „ | „ | 3·5 | 3·0 | 0·5 | 0·0010 | 0·0206 | 0·00494 | Nil |
| Dec. 5 | „ | Hazy | Slight | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0022 | 0·0296 | 0·03129 | „ |
| „ 12 | Straw | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0010 | 0·0268 | 0·0000 | „ |
| „ 19 | — | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0080 | 0·0226 | 0·00164 | „ |
| „ 26 | Amber | Cloudy | „ | „ | „ | „ | 7·0 | 6·9 | 0·1 | 0·0028 | 0·1460 | 0·03541 | „ |
| 1893. Jan. 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |

*ontinued.*

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. | | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols. 23–27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. 18. | Fixed. 19. | | | | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | ° C. |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1·3844 | 1·10 | 5·33 | 1·54 | 0·8734 | Trace | +0·2 | 1·60 | 1·60 | 1·60 | 1·60 | 1·60 | 17 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1·7222 | 0·95 | 5·19 | 4·21 | 1·0575 | Present | +1·35 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 17 |
| 1·6648 | 0·80 | 2·17 | 1·61 | 1·1738 | Nil | +0·7 | 1·40 | 1·60 | 1·60 | 1·60 | 1·60 | 15 |
| 1·8224 | 1·05 | 2·80 | 1·68 | 1·1743 | Trace | +0·8 | 1·30 | 1·30 | 1·30 | 1·30 | 1·30 | 18 |
| 1·7972 | 0·90 | 3·22 | 1·40 | 0·9514 | " | +1·1 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 16 |
| 3·8658 | 1·10 | 3·36 | 2·24 | 0·8901 | " | +1·4 | 2·20 | 2·20 | 2·20 | 2·20 | 2·20 | 17 |
| 2·6814 | 0·95 | 2·10 | 2·10 | 1·0787 | " | +0·8 | 1·40 | 1·40 | 1·40 | 1·40 | 1·40 | 14 |
| 2·5918 | 0·95 | 1·54 | 1·54 | 1·3404 | Nil | +0·6 | 0·80 | 0·80 | 0·80 | 0·80 | 0·80 | 13 |
| 2·9004 | 1·15 | 2·80 | 2·80 | 1·4179 | " | +1·25 | 2·40 | 2·40 | 2·40 | 2·40 | 2·40 | 11 |
| 1·4740 | 1·00 | 2·10 | 2·10 | 1·0884 | Trace | +0·7 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 8 |
| 2·3714 | 0·90 | 2·10 | 2·10 | 1·3016 | Nil | +0·7 | 1·30 | 1·30 | 1·30 | 1·30 | 1·30 | 13 |
| 1·3506 | 0·85 | 3·64 | 3·64 | 1·2699 | Trace | +1·5 | 2·00 | 2·40 | 2·40 | 2·80 | 2·80 | 14 |
| 0·8564 | 0·85 | 2·10 | 2·10 | 1·2018 | " | +0·8 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 17 |
| 1·2254 | 0·80 | 3·9 | 3·9 | 1·233 | Traces | +0·85 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 9 |
| 0·8402 | 0·925 | 8·2 | 5·5 | 1·039 | Trace | +0·8 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 10 |
| 1·0828 | 0·90 | 3·5 | 2·8 | 1·036 | " | +0·65 | 1·60 | 1·60 | 1·60 | 1·60 | 1·60 | 9 |
| 1·0600 | 0·95 | 3·3 | 3·3 | 1·262 | " | +0·45 | 0·90 | 0·90 | 0·90 | 0·90 | 0·90 | 11 |
| 1·1432 | 0·80 | 2·3 | 2·3 | 1·223 | " | +0·45 | 1·00 | 1·00 | 1·00 | 1·00 | 1·00 | 14 |
| 1·5820 | 1·30 | 6·4 | 6·4 | 1·029 | Abundant. | +2·4 | 1·40 | 1·40 | 1·40 | 1·40 | 1·40 | 4 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |

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* The sign + signifies positive acidity, and the sign — negative acidity or alkalinity.

TABLE IV.–

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1-2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1893.<br>Jan. 9 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 16 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 23 | Straw | Turbid | Considerable. | Acid | Acid | Acid | 4·0 | 3·5 | 0·5 | 0·0214 | 0·1048 | 0·04941 | Nil |
| „ 30 | „ | Hazy | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0020 | 0·0536 | 0·02470 | „ |
| Feb. 6 | Yellow | „ | — | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0024 | 0·0324 | 0·0000 | „ |
| „ 13 | „ | Clear | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0014 | 0·0222 | 0·02223 | „ |
| „ 20 | Amber | „ | — | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0012 | 0·0176 | 0·0000 | „ |
| „ 27 | | | | | | | | | | | | | No |
| Mar. 6 | Dk. straw | Clear | — | Acid | Acid | Acid | 5·0 | 4·5 | 0·5 | 0·0014 | 0·0303 | 0·01811 | Nil |
| „ 13 | P. amber | „ | — | „ | „ | „ | 3·0 | 2·5 | 0·5 | 0·0013 | 0·0256 | 0·0000 | „ |
| „ 20 | Straw | „ | — | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0014 | 0·0198 | 0·01152 | „ |
| „ 27 | Amber | Hazy | Slight | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0014 | 0·0392 | 0·00000 | „ |

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TABLE

Showing the RECORD of the CHEMICAL EXAMINATION

Results stated in

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As Nitrites. |
| 1-2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1891.<br>Nov. 9 | — | — | — | Acid | Acid | — | — | — | — | 0·0010 | 0·0310 | — | — |
| „ 16 | — | — | — | „ | „ | — | — | — | — | 0·0026 | 0·0400 | — | — |
| „ 23 | — | — | — | „ | „ | — | 9·0 | 6·0 | 3·0 | 0·0001 | 0·0420 | — | — |
| „ 30 | — | — | — | „ | „ | Acid | 4·0 | 3·0 | 1·0 | 0·0026 | 0·0310 | 0·0330 | — |

*continued.*

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. | | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols. 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. 18. | Fixed. 19. | | | | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | |
| — | — | — | — | — | — | — | — | — | — | — | — | °C.<br>— |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1·8248 | 0·90 | 3·50 | 2·10 | 0·8375 | Trace | +5·95 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 14 |
| 1·1752 | 0·90 | 3·92 | 3·92 | 1·0369 | „ | +0·8 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 14 |
| 1·0934 | 0·90 | 3·22 | 4·49 | 0·6696 | „ | +1·0 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 22 |
| 0·8790 | 1·20 | 5·47 | 4·77 | 1·0864 | Nil | +0·8 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 12 |
| 0·7286 | 0·975 | 4·35 | 4·35 | 1·3339 | Traces | +0·8 | 1·60 | 1·20 | 1·20 | 1·20 | 1·20 | 14 |

**water.**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0·9546 | 1·00 | 2·39 | 2·39 | 1·0864 | Nil | +0·8 | 1·60 | 1·60 | 1·60 | 1·60 | 1·60 | 13 |
| 1·1300 | 1·10 | 4·21 | 3·22 | 0·9224 | „ | +1·0 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 16 |
| 0·7724 | 1·15 | 3·36 | 3·36 | 0·9951 | A trace | +0·85 | 1·60 | 1·60 | 1·60 | 1·60 | 1·60 | 16 |
| 1·0324 | 0·70 | 4·91 | 3·92 | 1·4485 | Traces | +0·85 | 1·60 | 1·60 | 1·60 | 1·60 | 1·60 | 18 |

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## V.

## of WATER of BENTHAM MOSS POOL.

**Parts per 100,000.**

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. | | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols. 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. 18. | Fixed. 19. | | | | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | |
| — | 0·80 | 2·5 | — | 0·9870 | — | — | — | — | — | — | — | °C.<br>— |
| 2·1776 | 0·80 | — | — | 0·8004 | — | — | — | — | — | — | — | — |
| 1·7138 | 1·00 | 2·8 | — | — | — | — | 1·30 | 1·50 | 1·68 | 1·70 | 1·72 | 11 |
| 1·7644 | 1·00 | 5·5 | — | 0·9068 | — | — | 2·60 | 2·40 | 2·50 | 2·60 | 2·84 | 18 |

* The sign + signifies positive acidity, and the sign − negative acidity or alkalinity.

**TABLE V**

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free | Albuminoid. | Total. | As Nitrites. |
| 1-2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| 1891.<br>Dec. 7 | — | — | — | Acid | Acid | Acid | 7·5 | 5·5 | 2·0 | 0·0130 | 0·0410 | 0·0255 | — |
| „ 14 | Amber | Clear | V. slight | „ | „ | „ | 7·0 | 4·0 | 3·0 | 0·0050 | 0·038 | 0·0165 | Nil |
| „ 21 | Dk. brown | Much | Dk. brown. | „ | „ | „ | 9·7 | 5·5 | 4·2 | 0·0025 | 0·1080 | 0·0021 | „ |
| „ 28 | P. yellow | Clear | V. slight | „ | „ | „ | 9·0 | 7·0 | 2·0 | 0·0120 | 0·0570 | 0·0061 | „ |
| 1892.<br>Jan. 4 | Amber | Distinct | Peaty | „ | „ | „ | 10·0 | 5·8 | 4·2 | 0·0070 | 0·0806 | 0·0411 | Traces |
| „ 11 | „ | Much | „ | Neut. | Neut. | Neut. | 15·0 | 8·0 | 7·0 | 0·0260 | 0·1360 | 0·1111 | Nil |
| „ 18 | | | | | | | | | | | | No water to | |
| „ 25 | Straw | Slight | V. Slight | Acid | Acid | Acid | 7·0 | 5·0 | 2·0 | 0·0125 | 0·0490 | 0·0144 | Nil |
| Feb. 1 | „ | „ | „ | Neut. | Neut. | Neut. | 6·5 | 4·5 | 2·0 | 0·0037 | 0·0190 | 0·0247 | Traces |
| „ 8 | „ | „ | „ | „ | „ | „ | 8·5 | 5·0 | 3·5 | 0·0060 | 0·0790 | 0·0730 | Trace |
| „ 15 | „ | „ | Peat | Acid | Acid | Acid | 8·0 | 7·0 | 1·0 | 0·0045 | 0·1100 | 0·0576 | Nil |
| „ 22 | Amber | Much | „ | „ | „ | „ | 7·0 | 4·5 | 2·5 | 0·0055 | 0·0615 | 0·0391 | Trace |
| „ 29 | Straw | Clear | Slight | „ | „ | „ | 5·0 | 3·5 | 1·5 | 0·0035 | 0·0162 | 0·0123 | Nil |
| Mar. 7 | | | | | | | | | | | | | |
| „ 14 | | | | | | | | | | | | No water to | |
| „ 21 | | | | | | | | | | | | | |
| „ 28 | Greenish | Much | Moss | Acid | Acid | Acid | 6·0 | 5·0 | 1·0 | 0·0040 | 0·1170 | 0·0086 | Nil |
| Apr. 4 | Dk. amber | Cloudy | Peaty | „ | „ | „ | 10·5 | 8·5 | 1·5 | 0·0274 | 0·2780 | 0·0058 | „ |
| „ 11 | | | | | | | | | | | | | |
| „ 18 | | | | | | | | | | | | | |
| „ 25 | | | | | | | | | | | | No water to | |
| May 2 | | | | | | | | | | | | | |
| „ 9 | | | | | | | | | | | | | |
| „ 16 | | | | | | | | | | | | | |
| „ 23 | Yellow | Cloudy | Slight | Acid | Acid | Acid | 15·0 | 2·0 | 3·0 | 0·0020 | 0·0574 | 0·0659 | Nil |

*ed.*

| en ed n an- e at C. | Chlorine. 17. | Hardness. Total. 18. | Hardness. Fixed. 19. | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | Temperature of Water during Experiments recorded in Cols. 23–27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | ° C. |
| 32 | 0·70 | 0·8 | — | 0·9278 | — | — | 0·90 | 0·84 | 0·76 | 0·90 | 0·92 | 13 |
| 12 | 0·87 | 1·0 | — | 1·0130 | — | — | 0·60 | 0·60 | 0·80 | 0·82 | 1·10 | 14 |
| 22 | 0·90 | 3·6 | — | 1·0370 | — | — | 1·00 | 1·10 | 1·10 | 1·20 | 1·40 | 15 |
| 90 | 0·40 | 1·5 | — | 1·1034 | — | — | 0·80 | 0·90 | 1·00 | 0·90 | 1·00 | 15 |
| 98 | 0·90 | 4·0 | — | 0·9602 | — | — | 1·42 | 1·56 | 1·70 | 1·80 | 2·24 | 18 |
| 14 | 0·40 | 2·5 | — | — | — | — | 0·50 | 0·50 | 0·60 | 0·80 | 0·80 | 15 |

**ained.**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 98 | 0·90 | 1·5 | — | 1·2935 | Nil | — | 1·00 | 1·00 | 1·00 | 1·00 | 1·10 | 12 |
| 16 | 0·65 | 2·2 | — | 1·2555 | „ | — | 0·12 | 0·12 | 0·10 | 0·08 | 0·10 | 19 |
| 38 | 1·10 | 0·9 | — | 1·1510 | „ | — | 1·00 | 1·00 | 1·00 | 1·00 | 1·00 | 16 |
| 83 | 0·90 | 1·0 | — | 1·3320 | „ | — | 0·50 | 0·54 | 0·64 | 0·68 | 0·80 | 16 |
| 84 | 0·75 | 1·6 | — | — | „ | — | 1·00 | 1·00 | 1·00 | 1·00 | 1·00 | 14 |
| 40 | 0·85 | 1·3 | — | 1·2935 | — | — | 0·90 | 1·00 | 1·10 | 1·10 | 1·10 | 17 |

**ained.**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08 | 1·00 | 2·5 | 1·2 | 1·0780 | Nil | +1·0 | 0·12 | 0·14 | 0·16 | 0·18 | 0·18 | 12 |
| 00 | 1·20 | 6·5 | 3·0 | 0·5527 | „ | +1·8 | 0·30 | 0·32 | 0·32 | 0·36 | 0·40 | 16 |

**ained.**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1·10 | 3·9 | 1·3 | 0·7986 | Trace | +0·6 | 1·00 | 1·00 | [illegible] | [illegible] | [illegible] | 14 |

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* The sign + signifies positive acidity, and the sign – negative acidity or alkalinity

TABLE

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | Oxidized Nitrogen | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albuminoid. | Total. | As<br>tri |
| 1–2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 1 |
| 1892.<br>Nov. 21 | Amber | Hazy | Slight | Acid | Acid | Acid | 5·5 | 5·0 | 0·5 | 0·0038 | 0·0484 | 0·02964 | N |
| „ 28 | „ | „ | None | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0018 | 0·0500 | 0·0140 | „ |
| Dec. 5 | „ | „ | Mossy | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0024 | 0·1080 | 0·01893 | „ |
| „ 12 | „ | „ | Slight | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0014 | 0·0636 | 0·0000 | „ |
| „ 19 | „ | „ | „ | „ | „ | „ | 4·5 | 4·0 | 0·5 | 0·0056 | 0·0552 | 0·00823 | „ |
| „ 26 | „ | Cloudy | Floating matters. | „ | „ | „ | 14·0 | 13·5 | 0·5 | 0·0022 | 0·1594 | 0·01400 | „ |
| 1893.<br>Jan. 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 9 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| „ 16 | — | — | — | — | — | — | — | — | — | — | — | — | .. |
| „ 23 | Straw | Hazy | Slight | Acid | Acid | Acid | 4·0 | 3·5 | 0·5 | 0·0058 | 0·1104 | 0·05103 | Ni |
| „ 30 | Amber | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0030 | 0·1044 | 0·05202 | „ |
| Feb. 6 | „ | „ | „ | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0042 | 0·1074 | 0·01804 | „ |
| „ 13 | Straw | „ | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0014 | 0·0336 | 0·04094 | „ |
| „ 20 | Amber | Clear | — | „ | „ | „ | 5·0 | 4·5 | 0·5 | 0·0008 | 0·0784 | 0·05105 | „ |
| „ 27 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Mar. 6 | Straw | Hazy | — | Acid | Acid | Acid | 4·0 | 3·5 | 0·5 | 0·0014 | 0·0574 | 0·02223 | Ni |
| „ 13 | „ | „ | — | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0008 | 0·0346 | 0·01482 | „ |
| „ 20 | „ | „ | Mossy | „ | „ | „ | 4·0 | 3·5 | 0·5 | 0·0012 | 0·0207 | 0·01152 | „ |
| „ 27 | „ | „ | Slight | „ | „ | „ | 5·5 | 5·0 | 0·5 | 0·0018 | 0·0436 | 0·0000 | „ |

*continued.*

| Oxygen absorbed from Permanganate at 100° C. 16. | Chlorine. 17. | Hardness. | | Dissolved Oxygen. 20. | Iron. 21. | Acidity or Alkalinity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ or c.c. $\frac{n}{10}$ $H_2SO_4$ required to neutralize 100 c.c. of the Water.* 22. | Plumbo-solvency as shown by Amount of Lead taken up in Samples. | | | | | Temperature of Water during Experiments recorded in Cols 23-27. 28. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total. 18. | Fixed. 19. | | | | A. 23. | B. 24. | C. 25. | D. 26. | E. 27. | °C. |
| 1·4116 | 0·85 | 0·43 | 0·21 | 0·8550 | Present | +2·80 | 2·80 | 2·80 | 2·80 | 2·80 | 2·80 | 9 |
| 1·4400 | 0·85 | 0·70 | 0·40 | 0·6030 | Considerable. | +2·15 | 2·00 | 2·00 | 2·00 | 2·00 | 2·00 | 10 |
| 2·3138 | 0·95 | 0·78 | 0·40 | 0·6030 | " | +2·85 | 2·40 | 2·40 | 2·40 | 2·40 | 2·40 | 8 |
| 2·8000 | 0·90 | 0·88 | 0·57 | 0·952 | " | +2·5 | 2·40 | 2·40 | 2·40 | 2·40 | 2·40 | 11 |
| 1·6406 | 0·875 | 0·54 | 0·28 | 0·874 | " | +1·5 | 1·60 | 1·60 | 1·60 | 1·60 | 1·60 | 14 |
| 1·2698 | 1·50 | 1·21 | 1·21 | 0·825 | " | +4·4 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 4 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1·6272 | 0·85 | 2·80 | 2·80 | 1·2458 | Present | +0·75 | 0·40 | 0·40 | 0·40 | 0·40 | 0·40 | 13 |
| 1·5548 | 0·90 | 4·77 | 4·21 | 0·8454 | " | +1·45 | 1·40 | 1·40 | 1·40 | 1·40 | 1·40 | 14 |
| 2·3992 | 0·90 | 7·01 | 7·01 | 0·7445 | Abundant. | +2·65 | 0·60 | 0·60 | 0·60 | 0·60 | 0·60 | 22 |
| 0·8790 | 0·90 | 4·77 | 4·77 | 0·8300 | Present | +1·3 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 12 |
| 1·2412 | 1·00 | 5·19 | 5·19 | 0·7540 | " | +1·3 | 2·20 | 2·20 | 2·20 | 2·20 | 2·20 | 14 |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1·1958 | 0·45 | 4·77 | 3·50 | 0·8115 | Present | +1·5 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 13 |
| 1·0174 | 1·05 | 4·21 | 2·80 | 0·8061 | " | +1·55 | 1·80 | 1·80 | 1·80 | 1·80 | 1·80 | 16 |
| 0·6750 | 1·10 | 4·21 | 3·22 | 1·0654 | " | +1·0 | 1·20 | 1·20 | 1·20 | 1·20 | 1·20 | 18 |
| 0·6700 | 0·80 | 8·07 | 5·33 | 1·1079 | " | +1·15 | 1·40 | 1·40 | 1·40 | 1·40 | 1·40 | 19 |

* The sign + signifies positive acidity, and the sign − negative acidity or alkalinity.

### BENTHAM SPRING No. 1.

This water was examined at weekly intervals from Nov. 9, 1891, to March 21, 1892.

The results obtained are given in Table I., and may be summed up as follows:—

As regards total solids, free ammonia, albuminoid ammonia, oxidized nitrogen, oxygen absorbed from permanganate, chlorine, hardness, and dissolved oxygen, the average results were 6·74, 0·0073, 0·0254, 0·0473, 0·3474, 0·86, 3·02, and 0·9494 parts per 100,000 respectively. These results indicate that the water was a very soft water, yielding somewhat "high" results as regards albuminoid ammonia and oxygen absorbed from permanganate. The relatively small amount of free ammonia, and especially of chlorine, would indicate, what is in fact the case, that the source of the organic matter was largely vegetable in character.

The water was invariably found to be neutral in reaction.

Notwithstanding the neutral condition of the water, nearly all the samples were found to act, though only feebly, on lead. This may have been due, however, to the presence of some acid peaty water mixing with the neutral spring water. As has been said, it was found that occasionally surface peaty water gained access to this spring water, thereby introducing an uncertain element into the analysis. It may be noted, however, as another possible explanation, that it has been found that on other moorland gathering grounds that water issuing from the ground as spring water may sometimes possess a feeble and temporary plumbo-solvent* power. If such water is freely exposed to the air before being tested this circumstance is seldom, if ever, observed. In such cases it may be assumed that the spring water as it issues from the ground carries with it a slight excess of carbonic acid which becomes dissipated on exposure to the air. However this may be, the important point to be noted is this, namely, that the water of Bentham Spring No. 1 was uniformly neutral in reaction, and that the degree of its plumbo-solvency was so slight as to be negligible by comparison with other waters of totally different character presently to be dealt with.

### BENTHAM SPRING No. 2.

The water was examined at weekly intervals from November 9, 1891, to March 27, 1893, both dates inclusive.

The results obtained are given in the Table II. To a trifling extent Bentham Spring No. 2 was, like Spring No. 1, occasionally subject to contamination with surface water derived from the drainage of peaty soil. This circumstance, however, did not materially influence the value of the results in view of the sustained nature of the observations made.

The chief results may be summed up as follows:—

As regards total solids, free ammonia, albuminoid ammonia, oxidized nitrogen, oxygen absorbed from permanganate, chlorine, hardness, and dissolved oxygen, the average results, in round numbers, were 5·5, 0·006, 0·020, 0·025, 0·3, 0·9, 3·0, and 1·02 parts per 100,000 respectively.

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* *Plumbo-solvency:*—In the sense of this report plumbo-solvent power, plumbo-solvent ability, and plumbo-solvency are synonymous terms. They apply to the conspicuous property exhibited by certain waters to dissolve lead. Another kind of action on lead, which is to some extent comparable to the rusting of iron, will be dealt with separately, under the term "erosion."

These results differ in no conspicuous manner from those recorded under Bentham Spring No. 1.

Next as to the reaction of the various samples examined.

Five out of a total of sixty-six samples were slightly acid. The remaining sixty-one samples yielded a neutral reaction, and these samples were usually found to be possessed of a slight but still an appreciable amount of acid neutralizing* ability.

As regards plumbo-solvency, a number of the earlier samples acted *feebly* on lead, but in the main the water of Bentham Spring No. 2 was found to be free from appreciable plumbo-solvent ability.

Speaking in general terms, it may be said that the water of Bentham Spring No. 2 was neutral and possessed of slight but appreciable acid neutralizing ability, and that it was practically free from plumbo-solvent ability.

The chemical results are shown in graphic form in diagrams 24 to 37, appended to Part I. of this report.

### BENTHAM (BURNMOOR) PEAT POOL.

The water was examined at weekly intervals from November 9, 1891, to March 27, 1892, both dates inclusive.

The results obtained are given in Table IV., and may be summed up as follows:—

As regards total solids, free ammonia, albuminoid ammonia, oxidized nitrogen, oxygen absorbed from permanganate, chlorine, hardness, and dissolved oxygen, the average results in round numbers were 7·0, 0·005, 0·06, 0·03, 1·8, 0·9, 2·8, and 1·04 parts per 100,000 respectively.

These results differ in no striking manner from those recorded under Bentham Spring No. 1 and No. 2, except that the albuminoid ammonia and oxygen absorbed from permanganate was much greater in the peaty water than in the spring water, due to peaty matter both suspended and in solution.

Turning next to the records as regards reaction, the following facts are to be noted:—

In *forty-nine* out of fifty-three samples the water had an *acid reaction*; in the remaining four samples the water was neutral, a result in striking contrast to those obtained in the case of Bentham Springs.

The results as regards plumbo-solvency are no less striking.

Practically always the water of Bentham Peat Pool acted in vigorous fashion on lead, whereas the water of Bentham Spring No. 2 acted not at all or only very feebly.

The association on the one hand between the acidity and plumbo-solvent ability of the peaty water, and on the other hand between the neutral condition and lack of plumbo-solvent power of the spring water, is made very apparent by these results.

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* *Acid neutralizing Ability.*—In the sense of this report, negative acidity, alkalinity, and acid neutralizing ability are interchangeable terms. Probably no moorland water is alkaline in quite the same sense that other waters are unquestionably acid. Yet many of these waters possess a slight power of neutralizing acid waters. Perhaps the term "acid neutralizing ability" most clearly defines their position.

The chemical results are shown in graphic form in diagrams 1 to 12 at the end of Part I. of this report.

### BENTHAM (BURNMOOR) MOSS POOL.

The term "Moss" Pool requires some little explanation. Although in its immediate neighbourhood there was a greater abundance of moss than in the case of the peat pool, both were typically peaty waters, and indeed the term was used rather to avoid the possibility of any confusion arising between the two sets of samples than from any idea that the waters were intrinsically different in character.

The water was examined at weekly intervals from November 9, 1891, to March 27, 1893, both dates inclusive.

The results obtained are given in Table V., and may be summed up as follows:—

As regards total solids, free ammonia, albuminoid ammonia, oxidized nitrogen, oxygen absorbed from permanganate, chlorine, hardness, and dissolved oxygen, the average results in round numbers were 6·5, 0·005, 0·065, 0·028, 1·7, 0·92, 3·0, and 0·95 parts per 100,000 respectively.

As to reaction, in fifty-three out of fifty-six samples the water had an acid reaction; in the remaining three samples the water was neutral.

As regards plumbo-solvency, all the samples dissolved lead, and usually the action was very pronounced.

These results compare very closely with those of Bentham Peat Pool.

It is to be noted, however, that although the average results as regards degree of plumbo-solvency were nearly alike, namely, 1·4 in the case of Bentham Moss Pool and 1·3 in the case of Bentham Peat Pool, the average amount of acidity was 1·3 in the former, as compared with 0·75 in the latter. Possibly the water of Bentham Moss Pool contained more peaty matters and was more discoloured than Bentham Peat Pool, which would tend to make the results, as regards acidity, too high in relation to the plumbo-solvent ability of the water.

Unlike the spring waters, the water of Bentham Peat and Moss Pool usually contained iron. During the course of the inquiry (not only at Burnmoor, but on other gathering grounds) it was usually found that the greater the amount of acidity in water, the more iron was there apt to be present. The presence of iron, however, would seem to be commonly a concomitant factor, and not usually connected with the production of acid. Nevertheless, that this is not invariably the case will be shown later.

The chemical results as regards Bentham Moss Pool are shown in graphic form in diagrams 13 to 23 appended to Part I. of this report.

### BENTHAM (BURNMOOR) BRIGHT SYKE STREAM.

The water was examined at weekly intervals from March 28, 1892, to March 27, 1893, both dates inclusive.

The results obtained are given in Table III. The water of this stream, as has been already indicated, is to be regarded as a mixture in variable proportion (according to the season of the year, the rainfall, &c.) of peaty waters (*e.g.*, Bentham Peat and Moss Pool) and spring waters (*e.g.*, Bentham Spring No. 1 and No. 2).

The chief results may be summarised as follows :—

As regards total solids, free ammonia, albuminoid ammonia, oxidized nitrogen, oxygen absorbed from permanganate, chlorine, hardness, and dissolved oxygen, the average results in round numbers were 5·0, 0·005, 0·014, 0·023, 0·33, 0·9, 3·0, and 1·2 parts per 100,000 respectively.

These results differ in no material way from those recorded under Bentham Spring No. 1 and No. 2. They would seem to differ from those given under Bentham Peat and Moss Pools only as regards albuminoid ammonia and oxygen absorbed from permanganate, the figures being naturally "lower" owing to the presence of less vegetable matter.

In respect of reaction the water of Bentham Bright Syke Stream was invariably *neutral* (53 samples), and usually when appropriately tested it was found to have an appreciable power of neutralizing acid.

As regards plumbo-solvency, on four occasions the water displayed a *feeble* plumbo-solvent ability. In all the remaining samples (49 in number) the water was free from any solvent action on lead.

In respect of these negative qualities, it thus resembled Bentham Spring No. 2. It might have been expected that under special conditions the water of Bright Syke Stream would have been found possessed both of acidity and plumbo-solvency. Such a state of things might be produced by the first "washings" of the peat during a storm succeeding a period of drought. In such a case it may be assumed that there would be washed into the water supply, in concentrated form, acid substances produced in the peat *in situ*. Such acid substances, concentrated as regards acidity, and likewise large in bulk, might be expected to overcome the acid neutralizing ability of the spring water, now forming a *relatively* small proportion of the supply, owing to the superabundance of surface flood water.

Although, somewhat contrary to expectation, this did not happen in the course of the long period during which Bright Syke Stream was kept under observation, there can be no question of the fact that a stream of this kind, whose water is derived partly from peat and partly from springs, is capable of changing its character under the above conditions. This fact has since these experiments been verified on more than one gathering ground and on several occasions. And with regard to Bright Syke Stream it is tolerably clear that at times its water was practically on the border line: in a condition, that is, of instability as regards its power of dissolving lead.

The results of the chemical examination of the water of Bentham Bright Syke Stream are shown in graphic form in Diagrams 38 to 47 at the end of Part I. of this report.

## GENERAL CONCLUSIONS FROM THE RESULTS OBTAINED FROM EXAMINATION OF THE VARIOUS SELECTED WATERS AT BURNMOOR.

*Influence of Acidity.*—It will have been noted that, apart from reaction and action on lead, the various waters selected did not differ from each other in chemical composition to any notable extent, save as regards albuminoid ammonia and oxygen absorbed from permanganate, both of which were higher in the case of the waters with peaty origin. It is useful to put together in a table the chief average results of the analyses.

CHEMICAL EXAMINATION of the several selected BURNMOOR WATERS.
(Average results stated as parts per 100,000.)

| Chemical Composition as regards | Bentham Spring No. 2. | Bentham Peat Pool. | Bentham Moss Pool. | Bentham Bright Syke Stream. |
|---|---|---|---|---|
| Total solids - - | 5·5 | 7·0 | 6·5 | 5·0 |
| Free ammonia - - | 0·006 | 0·005 | 0·005 | 0·005 |
| Albuminoid ammonia - | 0·02 | 0·06 | 0·065 | 0·014 |
| Oxidized nitrogen - | 0·025 | 0·03 | 0·028 | 0·023 |
| Oxygen absorbed from permanganate. | 0·3 | 1·8 | 1·7 | 0·33 |
| Chlorine - - | 0·9 | 0·9 | 0·92 | 0·9 |
| Hardness - - - | 3·0 | 2·8 | 3·0 | 3·0 |
| Dissolved oxygen - | 1·02 | 1·04 | 0·96 | 1·2 |

Although on an average these waters differed from each other hardly at all as regards their chemical constituents, they nevertheless showed, in respect of their action on lead and their reaction, the most striking points of distinction. These facts may be emphasized in the following manner:—

| Reaction and Plumbo-Solvency. | Waters representative of *Moorland Springs and Streams* (mixture in variable proportion of spring and peaty waters). Bentham Springs and Bright Syke Stream. | Waters representative of *Moorland Peaty Water* unmixed (or nearly so) with Spring Water. Bentham Peat and Moss Pools. |
|---|---|---|
| Neutral waters and waters apt to be possessed as well of an appreciable amount of acid neutralizing ability. | + | − |
| Waters yielding an acid reaction and containing a measurable quantity of acid. | − | + |
| Waters practically free from any solvent action on lead. | + | − |
| Waters possessed of strong plumbo-solvent ability. | − | + |

These results, so far as they show mere association of acidity with plumbo-solvency, are, of course, not new. It has been noted on a number of occasions that moorland water supplies causing lead poisoning are apt to be acid. But, except by Dr. Sinclair White, no attempt has till now been made to establish how far acidity of itself is the essential factor in producing plumbo-solvency; whether varying degrees of plumbo solvent ability are associated with corresponding variations in acidity; or whether chemical conditions other than acidity also materially affect the power of an acid water to dissolve lead. Moreover, the conditions in nature which produce acidity had not been fully worked out in the past, and thus the primary source of plumbo-solvency could not be said to be fully understood.

It has been shown that, when the average results are taken, the peat pools and spring waters did not differ to any notable extent in their chemical composition, although the former were acid and dissolved lead, and that the latter were neutral and free from plumbo-solvent ability.

The inferences which may be drawn from these average results are greatly strengthened when the individual records are studied. The diagrams relating to the chemical composition of the peaty waters (peat and moss pools) from week to week, and from month to month, show that observed variations in the amount of this or the other chemical constituent of the waters has, in each instance, failed to account for the variability in the degree of lead-dissolving property.

When the variations in plumbo-solvency of the samples was contrasted respectively with their variations in composition as regards—

(1) total solids,
(2) organic matter,
(3) oxidized nitrogen,
(4) chlorine,
(5) hardness,
(6) dissolved oxygen,

no parallelism was in any case found to exist. Whereas, when acidity and plumbo-solvency are considered together, the relation was close. Taken as a whole the correspondence between the two conditions is quite unmistakable. It is true that the parallelism of amount of acidity and degree of plumbo-solvency was not always exact, either in the case of examination of multiple samples of a particular water, or when waters obtained from different sources were compared in respect of their qualities. It might have been anticipated that each water would probably possess its own standard of relation of lead-dissolving property to acidity, and that even in the case of a particular water, its own standard would be apt to fluctuate. The direct proportion between amount of acidity and degree of plumbo-solvency may quite easily depend upon variation in the nature of the acid present from time to time, or upon the controlling influence of some outside factor or factors difficult to ascertain and impossible to estimate. Moreover, it must be remembered that we are dealing with very slight degrees of acidity, the exact equivalent of which is by no means easy to determine, even by the most delicate test.* So, too, determination of the absolute degree of plumbo-solvency also presents

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* It might, perhaps, be surmised that methyl-orange would prove a more reliable indicator than phenol-phthalein in estimating quantitatively the acidity. But many moorland waters possessed of an appreciable solvent action on lead and showing distinct acid reaction when tested with lacmoid fail to give any evidence of acidity on testing with methyl-orange. In this connection it is well to remember that no

[*Note continued on page* 38.

difficulties. Although the most delicate available methods were designed for these estimations, and great care was taken, experimental error must be allowed for. It would, I think, be hardly surprising if, as a matter of actual fact, the effect of experimental error has been that the parallelism between acidity and plumbo-solvency has rather been masked than unduly displayed.

*Influence of Rainfall, Temperature, and Season.*—As an aid to the proper understanding of some of these matters, weekly records were kept of the rainfall, flow of the streams, and temperature (1 foot and 4 feet) of the soil on the Burnmoor gathering ground. But it soon became apparent that when dealing with one out of many tributary "feeders," the sum of which went to form a water supply, weekly meteorological records confined to one spot were hardly sufficient. Between each periodical visit to the gathering ground violent and sudden fluctuations occurred, of which no record could be obtained, and yet which were none the less of real importance. The meteorological observations available do not allow general inferences to be drawn other than of a tentative and provisional character. So far as the rainfall is concerned, the data are shown in the diagrams relating to the plumbo-solvent ability and acidity of Bentham Peat and Moss Pools, and it will be seen that no definite parallelism can be traced between the amount of rainfall and degree of plumbo-solvent ability, although possibly there is a slight indication of an inverse relation. But, in view of what has been said, failure from the available data to trace a direct relationship between the two must not be taken as proving that none exists.

For such a statement to be fully proved or disproved, daily, and during heavy rain hourly, records of rainfall would be needed, along with determination at corresponding intervals of the total yield of water and its acidity and ability to dissolve lead.

As regards season, the Burnmoor experiments indicate that acidity and plumbo-solvency are apt to be at their maximum in the late summer and autumn. But the question of season is necessarily complicated by the rainfall. In each year the curve of acidity and plumbo-solvency would tend to be dominated, not so much by seasonal variations of temperature as by the manner of distribution of the rainfall throughout the 12 months. The Burnmoor experiments, together with the result of examination of multiple gathering grounds elsewhere at different seasons of the year and under very variable conditions as regards the rainfall, permits of the following facts and inferences being put forward :—

Moorland waters (mixture of surface peaty water and spring water) are not unfrequently neutral during the summer months and acid during autumn, winter, and spring. This would seem to result from the fact that during summer the neutral spring water relative to the acid surface water is usually at its maximum, and that during the rest of the year these conditions are commonly reversed. In the first case we have a low rainfall, a high temperature, and a dry condition of the surface soil; in the second a high rainfall, a lower temperature, and a surface soil uniformly moist or sodden. This need not, however, prevent us from assuming that a high temperature provokes the production within certain limits of a greater amount of acid per unit of volume of water. For during warm seasons such water may be "held back" or "stored," as it

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moorland waters are ever strongly acid in reality, only relatively so. But in view of the circumstance that lead is very readily acted on by acids, that even the faintest trace of acid constitutes a source of danger owing to the ready solubility of the metal, and that lead poisoning is cumulative in character, I have found it convenient to use such terms as "very acid" or "strongly acid," but always in a relative sense.

were in the substance of the peat, or may escape in bulk too small to affect sensibly the reaction of the body of water constituting the water supply. Again, the low temperature may reasonably be supposed to retard the production of acid, while at the same time it lessens the evaporation, and so tends to keep the soil moist. Further, a moderate amount of rain may suffice to wash out of the peat acid substances previously manufactured without at the same time greatly diluting the acidity. On the other hand a prolonged and heavy rainfall may in time wash away the acid substances already stored in the peat, and at the same time greatly dilute the deleterious acid matter still remaining or in process of manufacture. Hence in the case of the moderate rainfall we may have a strongly acid water, but one small in total bulk, and in the case of the heavy and prolonged rainfall a water only feebly acid but enormous in quantity.

So far as actual observations are concerned, the most acid condition of moorland waters has been encountered during a storm following on a period of drought, and when the first "washings" of the peat were being carried into the supply.

The above by no means exhausts all the complex conditions which, to a greater or less degree, may bear on this question. For we may have wet summers and dry winters and cold summers and warm winters; we may have warm drying winds keeping the soil unduly dry irrespective of the rainfall, and, on the other hand, moist winds and mists retarding the evaporation from the soil. Again, some winters are conspicuous as regards snow, others in respect of frost. Lastly, the rainfall may be distributed pretty equally throughout the year or there may be long intervals during which there is no rain, followed by shorter periods of abnormal rainfall.

The following conclusions from the Burnmoor experiments may now be put forward :—

(1.) At Burnmoor the chemical composition of spring water, peaty water, and moorland spring (mixed) water, was very similar in respect of total solids, organic matter, oxidized nitrogen, chlorine, hardness, and dissolved oxygen, although peaty water gave the highest results as regards organic matter.

(2.) In the course of a series of examinations of spring water, peaty water, and moorland stream water, carried over many months, it was found that variations in chemical composition in respect of total solids, organic matter, oxidized nitrogen, chlorine, hardness, and dissolved oxygen were in no case accompanied by corresponding variations in plumbo-solvent ability.

(3.) In respect of acidity, however, there was in general a marked contrast between the several waters, which corresponded to observed differences between them in lead-dissolving property. Moreover, in the course of a long series of examinations carried over many months it was found that in the case of a given water variations in acidity were accompanied by corresponding variations in plumbo-solvent ability. And from these observations, since confirmed on a plurality of gathering grounds, it may be affirmed that in general—

(4.) Moorland spring water is neutral and free from plumbo-solvent ability. Commonly it is possessed as well of a slight but still an appreciable degree of acid neutralizing ability.

(5.) Moorland peaty water is usually distinctly acid and possessed of a vigorous solvent action on lead.

(6.) Moorland streams (mixture of spring and peaty water) are either neutral and free from plumbo-solvency, or acid, and possessed of plumbo-solvent ability.

The ability to dissolve lead of a given moorland water of mixed origin, such as a stream fed partly from springs and partly by surface and peaty water, depends upon the degree of the acidity possessed by its acid constituent waters, upon the volume of these acid constituent waters relative to the total bulk of mixed water, and upon the volume of the constituent waters which possess ability to neutralize acid. Here I may observe that laboratory experiments have shown conclusively that an acid peaty water may be deprived of its acidity and plumbo-solvency by admixture with sufficient quantity of moorland spring water possessed of acid neutralizing ability. Given a continuance of favourable counterbalancing conditions, a mixed water which constantly receives a proportion of highly acid water may nevertheless remain without ability to act upon lead.

## LATER EXPERIMENTS AT BENTHAM RESERVOIR, BURNMOOR.

During 1893 a further series of experiments were carried out at Burnmoor.

These comprised the chemical analysis, on lines broadly parallel with the previous investigations, of the water of Bentham Reservoir. The samples of water were collected both from near the surface and near the foot of the water in the reservoir.

Further the following waters were subjected to frequent bacterial testing, namely :—

Inflow water to Bentham Reservoir.
Surface water of Bentham Reservoir.
Water taken near the foot of Bentham Reservoir.
Peat Pool water.

Lastly, bacteriological examinations were made of numerous samples of Burnmoor peat soil.

### Chemical Examination of the Water of Bentham Reservoir.

It has already been pointed out that the Burnmoor supply to Bentham village was reputed to act on occasion vigorously on lead, and to have caused lead poisoning in the past. During the prolonged investigations carried out at Burnmoor which have been set out above, it was found that a tributary to this reservoir, Bright Syke Stream, did not become acid and possessed of plumbo-solvent ability, although certain of the contributory waters (Peat and Moss Pools) were strongly acid, and acted on lead to a conspicuous extent.

Bright Syke is not, however, the only source of supply of Bentham Reservoir, and in the circumstances it was considered advisable to ascertain whether this reservoir water did, as a matter of fact, occasionally acquire plumbo-solvent ability. For this purpose it was decided to subject to weekly chemical tests the sum of the waters collected from the Burnmoor gathering ground and stored in the reservoir, and it was decided to collect the samples both from near the surface and also from near the foot of the reservoir.

The records of the chemical examinations of the water obtained from near the (1) surface and (2) foot of Bentham Reservoir are shown in the following Tables VI. and VII.:—

## Showing the RECORD of the CHEMICAL EXAMINATION

Results st

| Date of Collection and of Examination. | Appearance. | | | Reaction with | | | Residue on Evaporation. | | | Ammonia. | | O Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Colour. | Turbidity. | Residue. | Cochineal. | Methyl Orange. | Lacmoid. | Total. | Loss on Ignition. | Fixed. | Free. | Albumenoid. | Total |
| 1898. Aug. 24 | Faint yellow. | Dim. | A slight brown deposit after standing for some time. | *Neu. | *Neu. | *Neu. | 10·0 | — | — | — | — | — |
| „ 30 | „ | „ | | „ | „ | „ | 10·0 | 6·0 | 4·0 | 0·008 | 0·008 | — |
| Sept. 6 | „ | „ | | „ | „ | „ | 9·0 | 4·0 | 5·0 | 0·004 | 0·012 | — |
| „ 13 | „ | „ | | „ | „ | „ | 10·5 | 4·5 | 6·0 | 0·003 | 0·009 | 0·032 |
| „ 20 | „ | „ | | „ | „ | „ | 10·0 | 4·0 | 6·0 | 0·003 | 0·016 | 0·043 |
| „ 27 | „ | „ | | „ | „ | „ | 10·0 | 5·0 | 5·0 | 0·006 | 0·024 | 0·009 |
| Oct. 4 | „ | „ | | „ | „ | „ | 8·5 | 3·0 | 5·5 | 0·005 | 0·024 | Trace |
| „ 11 | „ | „ | | „ | „ | „ | 8·5 | 3·5 | 5·0 | 0·004 | 0·020 | 0·041 |
| „ 18 | „ | „ | | „ | „ | „ | 7·5 | 3·0 | 4·5 | 0·006 | 0·020 | 0·029 |
| „ 25 | „ | „ | | „ | „ | „ | 6·5 | 3·0 | 3·5 | 0·003 | 0·016 | 0·030 |
| Nov. 1 | „ | „ | | „ | „ | „ | 8·0 | 3·5 | 4·5 | 0·004 | 0·012 | 0·016 |
| „ 8 | „ | „ | | „ | „ | „ | 8·0 | 3·0 | 5·0 | 0·004 | 0·010 | Trace |
| „ 15 | „ | „ | | „ | „ | „ | 9·0 | 4·0 | 5·0 | 0·006 | 0·007 | 0·016 |
| „ 22 | „ | „ | | „ | „ | „ | 10·5 | 3·5 | 7·0 | 0·004 | 0·008 | 0·016 |
| „ 29 | „ | „ | | „ | „ | „ | 11·0 | 6·0 | 6·0 | 0·003 | 0·014 | 0·000 |
| Dec. 6 | „ | „ | | „ | „ | „ | 7·0 | 3·0 | 4·0 | 0·003 | 0·010 | 0·000 |
| „ 13 | „ | „ | | „ | „ | „ | 6·0 | 4·0 | 2·0 | 0·004 | 0·012 | 0·000 |
| „ 20 | „ | „ | | „ | „ | „ | 7·0 | 3·0 | 4·0 | 0·002 | 0·010 | 0·000 |
| „ 27 | „ | „ | | „ | „ | „ | 8·0 | 3·0 | 5·0 | 0·004 | 0·006 | 0·000 |

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* As the water of Bentham Reservoir was said to occasionally have an acid reaction, samples were coll
9, 10, 12, 13, 14, 16, 17, 19, 20, 21, 23, 24, 28; Nov. 4, 11, 18, 25. The water, however, was always found to

† The hardness of this water was found to be either unaffected by boiling, or to be slightly increased in

obtained from near the Foot of **Bentham Reservoir.**

r 100,000.

| Chlorine. | Hardness. | | Dissolved Oxygen. | Iron. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralize 100 c.c. of the Water. | Plumbo-solvency, as shown by amount of Lead taken up in Samples. The action on Lead was tested by Upward Filtration through 50 c.c. washed Lead Shot. | | | | | | Meteorological Data. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total. | Fixed. | | | | 1st. 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. | Rainfall, Inches. | Temperature, 1 ft. Therm. ° F. | Temperature, 4 ft. Therm. ° F. |
| 1·2 | — | † | — | — | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | — | — | — |
| 1·1 | — | — | 1·13 | — | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·15 | 55 | 54 |
| 1·1 | 6·7 | — | 1·14 | — | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·85 | 54 | 53 |
| 1·1 | 6·6 | — | 1·20 | — | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·02 | 55 | 53 |
| 1·2 | 6·2 | — | 1·15 | Trace | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·67 | 52 | 52 |
| 1·2 | 5·5 | — | 1·11 | „ | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·61 | 52 | 52 |
| 1·0 | 4·6 | — | 1·10 | „ | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 3·29 | 50 | 50 |
| 1·1 | 4·3 | — | 1·31 | 0·0 | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·32 | 49 | 50 |
| 1·2 | 3·9 | — | 1·22 | Trace | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 2·18 | 48 | 48 |
| 1·1 | 3·9 | — | 1·23 | 0·0 | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·16 | 48 | 47 |
| 1·1 | 5·3 | — | 1·30 | Trace | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·75 | 47 | 46 |
| 1·3 | 4·3 | — | 1·37 | 0·0 | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·99 | 44 | 46 |
| 1·1 | 4·2 | — | 1·35 | „ | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·04 | 45 | 45 |
| 1·2 | 5·0 | — | 1·38 | „ | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·84 | 45 | 44 |
| 1·2 | 4·1 | — | 1·34 | „ | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·08 | 42 | 44 |
| 1·2 | 4·6 | — | 1·20 | Trace | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 0·39 | 44 | 44 |
| 1·2 | 4·5 | — | 1·30 | 0·0 | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 2·42 | 44 | 44 |
| 1·2 | 4·9 | — | 1·28 | Trace | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·79 | 42 | 44 |
| 1·1 | 4·6 | — | 1·32 | 0·0 | „ | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 1·59 | 43 | 44 |

**dates besides those given:—Sept. 8, 9, 11, 12, 14, 15, 16, 18, 19, 21, 22, 23, 25, 26, 28, 29, 30; Oct. 2, 3, 5, 6,**
**ion.**

In summary of the above results the following points are worthy of note:—

The samples of water obtained from near the foot of the reservoir and those collected from near the surface did not differ the one from the other to any notable extent in their chemical composition. And although they were less "soft," and contained more solids, they did not seem to differ much in other respects from the waters which have been considered in detail in the earlier part of this report. As regards reaction and action on lead, both sets of samples were found to be invariably neutral and free from plumbo-solvency.

Samples were collected for detailed examination at weekly intervals from August 4 to December 27, 1893, both dates inclusive. Samples were also collected on 39 other occasions during September, October, and November 1893, and these were tested for their reaction. The water, however, was always found to be neutral.

In connexion with the above tables it will be noted that certain meteorological data are given. These were obtained from instruments placed on the gathering ground in close relation to Bentham Peat and Moss Pools.

During the whole period of observation, therefore, Bentham Reservoir was proved to have no solvent action upon lead. The result was not altogether what had been anticipated, in view of the general statements which had been made before 1893 as to the lead-dissolving properties possessed by this water, and for the purposes of this inquiry it is rather a matter for regret that it did not become plumbo-solvent during the period of my observation. The results obtained, however, are not without value in their negative aspects. They furnish a good example of a moorland water supply which may be neutral and free from action on lead, although certain of its contributory waters are possessed of acidity and plumbo-solvency in conspicuous degree. Here, as in the case of Bright Syke Stream, there can be little doubt of the reason.

The result is to be traced to the presence in sufficient amount of other contributory waters of different sort, namely, neutral spring waters, and waters, moreover, possessed of an appreciable degree of acid neutralizing ability. Obviously conditions might at times arise which disturb the balance, and if as a fact Bentham Reservoir at other times has been acid and possessed of ability to dissolve lead, the circumstance is not necessarily inconsistent with the facts observed in 1893.

## BACTERIOLOGICAL EXAMINATION OF BURNMOOR WATERS.

It is convenient first to record the results of bacteriological examination of the inflow water to *Bentham Reservoir* and the water of the reservoir collected both from near the foot of the reservoir and near the surface.

## TABLE VIII.

### RESULTS of the BACTERIOLOGICAL ANALYSIS of the INFLOW WATER to BENTHAM RESERVOIR.

| Experiment. | Description of the Sample of Water. | Date of Collection and of Examination. | Number of c.c. added to the nutrient Gelatin. | Number of Experiments. | Average Number of Microbes in 1 c.c. of the Water. |
|---|---|---|---|---|---|
| | | 1893. | c.c. | | |
| 1 | Peaty water, inflow to Bentham Reservoir - | Aug. 24 | 0·5 | 3 | 1,272 |
| 2 | „ „ „ „ „ - - | „ 30 | 0·3 | 2 | 504 |
| 3 | „ „ „ „ „ - - | Sept. 6 | 0·166 | 2 | 1,674 |
| 4 | „ „ „ „ „ - - | „ 13 | 0·11 | 2 | 378 |
| 5 | „ „ „ „ „ - - | „ 20 | 0·11 | 2 | 1,368 |
| 6 | „ „ „ „ „ - - | „ 27 | 0·11 | 2 | 1,134 |
| 7 | „ „ „ „ „ - - | Oct. 4 | 0·11 | 2 | 5,850 |
| 8 | „ „ „ „ „ - - | „ 11 | 0·11 | 2 | 1,098 |
| 9 | „ „ „ „ „ - - | „ 18 | 0·11 | 2 | 2,826 |
| 10 | „ „ „ „ „ - - | „ 25 | 0·056 | 1 | 792 |
| 11 | „ „ „ „ „ - - | Nov. 1 | 0·08 | 2 | 11,175 |
| 12 | „ „ „ „ „ - - | „ 8 | 0·08 | 2 | 600 |
| 13 | „ „ „ „ „ - - | „ 15 | 0·08 | 2 | 700 |
| 14 | „ „ „ „ „ - - | „ 22 | 0·08 | 2 | 4,150 |
| 15 | „ „ „ „ „ - - | „ 29 | 0·08 | 2 | 1.175 |
| 16 | „ „ „ „ „ - - | Dec. 6 | 0·08 | 2 | 1,425 |
| 17 | „ „ „ „ „ - - | „ 13 | 0·08 | 2 | * |
| 18 | „ „ „ „ „ - - | „ 20 | 0·12 | 2 | 1,712 |
| 19 | „ „ „ „ „ - - | „ 27 | 0·08 | 2 | 700 |
| | | Average number of microbes - | | - | 2,140 |

* Liquefying colonies too numerous to allow of accurate counting.

## TABLE IX.

### RESULTS of the BACTERIOLOGICAL ANALYSIS of the SURFACE WATER of BENTHAM RESERVOIR.

| Experiment. | Description of the Sample of Water. | Date of Collection and of Examination. | Number of c.c. added to the Nutrient Gelatin. | Number of Experiments. | Average number of microbes in 1 c.c. of the Water. |
|---|---|---|---|---|---|
| | | 1893. | c.c. | | |
| 1 | Surface (peaty) water, Bentham Reservoir - | Aug. 24 | 0·86 | 3 | * |
| 2 | „ „ „ „ - | „ 30 | 0·167 | 2 | 528 |
| 3 | „ „ „ „ - | Sept. 6 | 0·21 | 2 | 553 |
| 4 | „ „ „ „ - | „ 13 | 0·08 | 2 | 1,944 |
| 5 | „ „ „ „ - | „ 20 | 0·08 | 2 | 888 |
| 6 | „ „ „ „ - | „ 27 | 0·08 | 2 | 3,984 |
| 7 | „ „ „ „ - | Oct. 4 | 0·08 | 2 | 3,648 |
| 8 | „ „ „ „ - | „ 11 | 0·04 | 1 | 840 |
| 9 | „ „ „ „ - | „ 18 | 0·08 | 2 | 2,784 |
| 10 | „ „ „ „ - | „ 25 | 0·08 | 2 | 456 |
| 11 | „ „ „ „ - | Nov. 1 | 0·074 | 2 | 2,133 |
| 12 | „ „ „ „ - | „ 8 | 0·037 | 1 | 2,916 |
| 13 | „ „ „ „ - | „ 15 | 0·037 | 1 | 1,080 |
| 14 | „ „ „ „ - | „ 22 | 0·074 | 2 | 1,134 |
| 15 | „ „ „ „ - | „ 29 | 0·074 | 2 | 4,698 |
| 16 | „ „ „ „ - | Dec. 6 | 0·037 | 1 | 837 |
| 17 | „ „ „ „ - | „ 13 | 0·074 | 2 | * |
| 18 | „ „ „ „ - | „ 20 | 0·074 | 2 | 1,750 |
| 19 | „ „ „ „ - | „ 27 | 0·074 | 2 | 1,485 |
| | Average number of microbes - - | | | | 1,862 |

* Liquefying colonies too numerous to allow of accurate counting.

## TABLE X.

### RESULTS of the BACTERIOLOGICAL ANALYSIS of the WATER at the FOOT of BENTHAM RESERVOIR.

| Experiment. | Description of the Sample of Water. | Date of Collection and of Examination. | Number of c.c. added to the Nutrient Gelatine. | Number of Experiments. | Average number of microbes in 1 c.c. of the Water. |
|---|---|---|---|---|---|
| | | 1893. | c.c. | | |
| 1 | Peaty water, foot of Bentham Reservoir - - | Aug. 24 | — | — | — |
| 2 | - - - - - - | „ 30 | 0·223 | 2 | * |
| 3 | - - - - - - | Sept. 6 | 0·285 | 2 | 518 |
| 4 | - - - - - - | „ 13 | 0·14 | 2 | 1,456 |
| 5 | - - - - - - | „ 20 | 0·14 | 2 | 2,394 |
| 6 | - - - - - - | „ 27 | 0·14 | 2 | 1,554 |
| 7 | - - - - - - | Oct. 4 | 0·07 | 1 | 9,520 |
| 8 | - - - - - - | „ 11 | 0·14 | 2 | 1,038 |
| 9 | - - - - - - | „ 18 | 0·14 | 2 | 1,484 |
| 10 | - - - - - - | „ 25 | 0·14 | 2 | 443 |
| 11 | - - - - - - | Nov. 1 | 0·06 | 1 | 5,888 |
| 12 | - - - - - | „ 8 | 0·12 | 2 | 2,906 |
| 13 | - - - - - - | „ 15 | 0·06 | 1 | 736 |
| 14 | - - - - - - | „ 22 | 0·12 | 2 | 1,072 |
| 15 | - - - - - - | „ 29 | 0·12 | 2 | 4,416 |
| 16 | - - - - - - | Dec. 6 | 0·12 | 2 | 1,632 |
| 17 | - - - - - - | „ 13 | 0·12 | 2 | * |
| 18 | - - - - - - | „ 20 | 0·08 | 2 | 2,754 |
| 19 | - - - - - - | „ 27 | 0·12 | 2 | 1,360 |
| | | Average number of microbes * - - | | | 2.446 |

* Liquefying colonies too numerous to allow of accurate counting.

These results, together with records as regards the rainfall, are shown in diagram 47.

The average number of microbes in the various waters was as follows:—

| | |
|---|---|
| Inflow water to Bentham Reservoir. Microbes per c.c. | 2,140 |
| Surface water of Bentham Reservoir. Microbes per c.c. - - - - - - - | 1,162 |
| Water at the foot of Bentham Reservoir. Microbes per cc. - - - - - - | 2,446 |

It will be noted that the number of microbes was large in all the waters, that the inflow water contained more bacteria than the surface water, and that the water collected from near the foot of the reservoir contained the largest number of micro-organisms.

A reference to diagram 47 would seem to show that a rise or fall above or below the mean in the number of bacteria in one or other, or in all three, of the samples, was usually associated with corresponding wet or dry weather.

To some extent there was a parallelism between the number of bacteria in the individual samples obtained from the three sources on comparable dates, and this measure of correspondence seemed to be best seen in the case of the reservoir samples.

As regards the kinds of bacteria found in the various waters, these did not seem to be widely different either the one from the other or from the bacterial flora of most potable waters. B. fluorescens liquefaciens was usually present in great numbers, and three distinct varieties of B. fluorescens non-liquefaciens were frequently met with in the cultivations. Occasionally B. ianthinus, B. arborescens, proteus-like forms, B. subtilis, B. mesentericus, cladothrix dichotoma, &c., were noted.

It is of interest, in the next place, to contrast the above results with those obtained during the bacteriological examination of *Burnmoor Peat Pool* water, shown in Table XVI. of the series which follows:—

## TABLE XI.

Showing the RESULTS of the BACTERIOLOGICAL ANALYSIS of BENTHAM PEAT SOIL for AEROBIC MICRO-ORGANISMS.

The samples of peat soil were taken from a little below (a few inches) the surface.

| Experiment. | Description of the Sample of Peat Soil. | Date of Collection and of Examination. | Amount of Dilution of the Peat with sterile Water. Grams. in 500 c.c. sterile Water. | Number of Experiments. | Number of c.c. Soil Mixture added to the nutrient Gelatin. | Average Number of microbes in 1 Gramme of the Peat Soil. | Percentage amount of Moisture in the Peat. |
|---|---|---|---|---|---|---|---|
| A. | Bentham peat soil (a little below surface level). | 1893.<br>Nov. 8 | 4·233 | 2 | c.c.<br>0·07 | 24,500 | %<br>82 |
| B. | " " " " " " - | " 15 | 5·292 | 2 | 0·40 | 73,000 | 91 |
| C. | " " " " " " - | " 22 | 4·297 | 2 | 0·35 | 48,860 | 67 |
| D. | " " " " " " - | " 29 | 4·04 | 2 | 0·35 | 31,000 | 82 |
| E. | " " " " " " - | Dec. 6 | 5·201 | 2 | 0·175 | 40,350 | 64 |
| F. | " " " " " " - | " 13 | 7·024 | 1 | 0·35 | 12,000 | 74 |
| G. | " " " " " " - | " 20 | 3·573 | 2 | 0·35 | 50,900 | 84 |
| H. | " " " " " " - | " 27 | 7·894 | 2 | 0·35 | 31,900 | 87 |
|  | Average of 15 experiments with 8 samples of peat soil - - - |  |  |  |  | 39,063 | 79 %<br>=average moisture. |

## TABLE XII.

### Showing the RESULTS of the BACTERIOLOGICAL ANALYSIS of BENTHAM PEAT SOIL for ANAEROBIC MICRO-ORGANISMS.

**The samples of peat were taken from the surface layers.**

| Experiment. | Description of the Sample of Peat Soil. | Date of Collection and of Examination. | Amount of Dilution of the Peat with sterile Water. Grams. in 500 c.c. Water. | Number of Experiments. | Number of c.c. Soil Mixture added to the nutrient Gelatin. | Average Number of microbes in 1 Gramme of the Peat Soil. | Percentage amount of Moisture in the Peat. |
|---|---|---|---|---|---|---|---|
| | | 1893. | | | c.c. | | % |
| A. | Bentham peat soil (surface level) - | Sept. 6 | 4·599 | 1 | 1 | * | 78 |
| B. | „ „ „ „ - | „ 13 | 6·667 | 2 | 2 | * | 56 |
| C. | „ „ „ „ - | „ 20 | 12·628 | 1 | 1 | 1,660 | 78 |
| D. | „ „ „ „ - | „ 27 | 10·502 | 1 | 1 | * | 71 |
| E. | „ „ „ „ - | Oct. 4 | 8·902 | 1 | 1 | 2,450 | 81 |
| F. | „ „ „ „ - | „ 11 | 6·088 | 1 | 1 | 2,290 | 81 |
| G. | „ „ „ „ - | „ 18 | 6·776 | 1 | 1 | 6,750 | 79 |
| H. | „ „ „ „ - | „ 25 | 4·934 | 1 | 1 | 6,650 | 75 |
| I. | „ „ „ „ - | Nov. 1 | 6·975 | 1 | 1 | 5,000 | 87 |
| J. | „ „ „ „ - | „ 8 | 12·765 | 1 | 1 | 13,150 | 88 |
| K. | „ „ „ „ - | „ 15 | 8·026 | 1 | 1 | * | 74 |
| L. | „ „ „ „ - | „ 22 | 6·446 | 1 | 1 | 41,000 | 71 |
| M. | „ „ „ „ - | „ 29 | 9·180 | 1 | 1 | 15,500 | 82 |
| N. | „ „ „ „ - | Dec. 6 | 14·335 | 1 | 1 | 1,700 | 87 |
| O. | „ „ „ „ - | „ 13 | 11·153 | 1 | 1 | 5,100 | 71 |
| P. | „ „ „ „ - | „ 20 | 8·142 | 1 | 1 | 795 | 87 |
| Q. | „ „ „ „ - | „ 27 | 18·937 | 1 | 1 | 1,765 | 82 |
| | Average number of anaerobic bacteria | - | - | - | - | 7,985 | |

* The experiment failed.

## TABLE XIII.

### Showing the RESULTS of the BACTERIOLOGICAL ANALYSIS of BENTHAM PEAT SOIL for AEROBIC MICRO-ORGANISMS.

The samples of peat were taken from the surface layers.

| Experiment. | Description of the Sample of Peat Soil. | Date of Collection and of Examination. | Amount of Dilution of the Peat with sterile Water. Grams. in 500 c.c. Water. | Number of Experiments. | Number of c.c. Soil Mixture added to the nutrient Gelatin. | Average Number of microbes in 1 Gramme of the Peat Soil. | Percentage Amount of Moisture in the Peat. |
|---|---|---|---|---|---|---|---|
| | | 1898. | | | c.c. | | % |
| 1 | Bentham peat soil (surface level) | Aug. 8 | 1·3 | 3 | 0·72 | 62,000 | 82 |
| 2 | ,, ,, ,, - | ,, 8 | 4·0 | 3 | 0·72 | 36,000 | 90 |
| 3 | ,, ,, ,, - | ,, 30 | 4·543 | 2 | 0·44 | 152,000 | 69 |
| 4 | ,, ,, ,, - | ,, 30 | 3·965 | 2 | 0·44 | 276,500 | 65 |
| 5 | ,, ,, ,, - | Sept. 6 | 4·599 | 2 | 0·166 | 428,500 | 78 |
| 6 | ,, ,, ,, - | ,, 6 | 10·429 | 2 | 0·166 | 373,500 | 81 |
| 7 | ,, ,, ,, - | ,, 13 | 6·667 | 2 | 0·122 | 183,500 | 56 |
| 8 | ,, ,, ,, - | ,, 13 | 3·847 | 2 | 0·122 | 119,500 | 67 |
| 9 | ,, ,, ,, - | ,, 20 | 12·628 | 2 | 0·08 | 29,500 | 78 |
| 10 | ,, ,, ,, - | ,, 20 | 11·422 | 2 | 0·112 | 111,500 | 81 |
| 11 | ,, ,, ,, - | ,, 27 | 10·502 | 2 | 0·08 | 114,000 | 71 |
| 12 | ,, ,, ,, - | ,, 27 | 3·61 | 2 | 0·112 | 149,500 | 70 |
| 13 | ,, ,, ,, - | Oct. 4 | 8·902 | 2 | 0·08 | 223,000 | 81 |
| 14 | ,, ,, ,, - | ,, 4 | 6·362 | 2 | 0·112 | 250,000 | 83 |
| 15 | ,, ,, ,, - | ,, 11 | 6·088 | 3 | 0·12 | 164,000 | 81 |
| 16 | ,, ,, ,, - | ,, 11 | 5·420 | 2 | 0·12 | 104,400 | 81 |
| 17 | ,, ,, ,, - | ,, 18 | 6·776 | 3 | 0·12 | 161,250 | 79 |
| 18 | ,, ,, ,, - | ,, 18 | 5·510 | 3 | 0·152 | 88,000 | 75 |
| 19 | ,, ,, ,, - | ,, 25 | 4·934 | 2 | 0·08 | 126,500 | 75 |
| 20 | ,, ,, ,, - | ,, 25 | 6·745 | 2 | 0·112 | 1,044,500 | 74 |
| 21 | ,, ,, ,, - | Nov. 1 | 6·975 | 3 | 0·12 | 440,500 | 87 |
| 22 | ,, ,, ,, - | ,, 1 | 11·150 | 2 | 0·07 | 180,500 | 80 |
| 23 | ,, ,, ,, - | ,, 8 | 12·765 | 2 | 0·08 | 141,950 | 88 |
| 24 | ,, ,, ,, - | ,, 15 | 8·026 | 2 | 0·07 | 179,500 | 74 |
| 25 | ,, ,, ,, - | ,, 22 | 6·446 | 2 | 0·08 | 137,500 | 71 |
| 26 | ,, ,, ,, - | ,, 29 | 9·18 | 2 | 0·08 | 103,750 | 82 |
| 27 | ,, ,, ,, - | Dec. 6 | 14·335 | 2 | 0·08 | 256,000 | 87 |
| 28 | ,, ,, ,, - | ,, 13 | 11·153 | 1 | 0·04 | 24,500 | 71 |
| 29 | ,, ,, ,, - | ,, 20 | 8·142 | 2 | 0·08 | 35,300 | 87 |
| 30 | ,, ,, ,, - | ,, 27 | 13·937 | 2 | 0·08 | 36,950 | 82 |
| | Average of 65 experiments with 30 samples of peat soil - | | | | | 191,153 = average | 77 per cent. moisture. |

## TABLE XIV.

## LIST of MICRO-ORGANISMS isolated from BENTHAM PEAT SOIL.

| Micro-Organisms isolated and identified. | Remarks. |
|---|---|
| Bacillus mycoides | This micro-organism, which is commonly met with in cultivated soil, is comparatively rare in peat soil. |
| Bacillus fluorescens liquefaciens | As compared with peat water cultivation, uncommon in peat soil. |
| Bacillus fluorescens non-liquefaciens, A. | Two distinct varieties. |
| " " " B. | |
| Bacillus subtilis | These two organisms can usually be obtained by heating a mixture of peat and water to 80° C., and then inoculating nutrient gelatin with a considerable quantity of the soil mixture. |
| Potato Bacillus (a variety of Bacillus mesentericus vulgatus). | |
| Bacillus gasoformans (?) | Not nearly so common as in peat water cultivations. |
| Bacillus arborescens | Not very commonly met with. |
| Proteus-like forms | |
| Saccharomycetes. Pink and white torulae | Unlike peat water, peat soil is rich in yeast and mould fungi. They are, no doubt, derived from the air and find in surface peat soil a suitable nidus owing to its moist character and acid re-action. |
| Hyphomycetes. Many different forms. | |

A large number of other micro organisms not identified. A full description of two of these will be found elsewhere.

## TABLE XV.

## LIST of MICRO-ORGANISMS isolated from CULTIVATIONS of BENTHAM PEAT WATER.

| Micro-Organisms isolated and identified. | Remarks. |
|---|---|
| Bacillus fluorescens liquefaciens | Very commonly met with. |
| Bacillus fluorescens non-liquefaciens, A. | Three distinct varieties of this organism frequently encountered. |
| " " B. | |
| " " C. | |
| Bacillus arborescens (? A.) | It is a question if there are not two varieties of this organism, differing slightly in their biological characters. |
| " " (? B.) | |
| Bacillus subtilis | Not commonly met with. |
| Bacillus figurans | |
| Proteus-like forms { Proteus vulgaris (?) | The P. mirabilis was very rarely noticed. |
| Proteus-like forms { Proteus mirabilis | |
| Bacillus gasoformans (?) | Very common. |
| Bacillus ianthinus | Met with fairly often. |
| Micrococcus cinnabareus | Rare. |
| Cladothrix dichotoma | |
| Yeast colonies and moulds | Occasionally met with. |

A considerable number of other micro-organisms were isolated, but their identification was not considered sufficiently certain to allow of their introduction into this table.

## TABLE XVI.

### RESULTS of the BACTERIOLOGICAL ANALYSIS of the WATER of BENTHAM PEAT POOL.

| Samples. | Description of the Sample of Water. | Date of Collection and of Examination. | Number of c.c. added to the nutrient Gelatin. | Number of Experiments. | Average Number of microbes in 1 c.c. of the Water. |
|---|---|---|---|---|---|
| | | 1893. | c.c. | | |
| A. | Acid water of Bentham Peat Pool - - - | Nov. 8 | 0·17 | 2 | 312 |
| B. | " " " " - - | " 15 | 0·34 | 2 | 60 |
| C. | " " " " - - - | " 22 | 0·18 | 2 | 441 |
| D. | " " " " - - | " 29 | 0·13 | 2 | 216 |
| E. | " " " " - - - | Dec. 6 | 0·34 | 2 | 60 |
| F. | " " " " - - - | " 13 | 0·17 | 1 | 312 |
| G. | " " " " - - - - | " 20 | 0·16 | 2 | 44 |
| H. | " " " " - - - | " 27 | 0·34 | 2 | 60 |
| | Average of 15 experiments with 8 samples of water - - - | | | | 180 |

As regards Bentham Peat Pool (Table XVI.), it is to be noted that the average number of microbes was only 180 per c.c., and that half the number of samples contained less than 100 bacteria in 1 c.c.

This water, it will be remembered, was known to be habitually acid, and it is possible that the acidity inhibited bacterial growth. The inflow water to Bentham Reservoir, on the other hand, was always neutral, and was a mixture in variable proportion of surface peaty water and spring water. It is difficult to explain the great difference in the number of bacteria in these two waters simply on the ground of difference of reaction as regards acidity, particularly as the peat pool water contained more organic matter, although this was chiefly, if not entirely, of vegetable origin. It is indeed possible that the water collected on the gathering ground became subsequently contaminated on its way to the reservoir: and this conjecture receives some support from the fact that the water supplying Bentham Reservoir flows near to a farmhouse. However this may be, it is important to note that a water representing rainfall-water that had remained in prolonged contact with peat and decaying vegetable organic matter did not contain a large number of microbes.

As to the kinds of bacteria found in the cultivations, these did not seem to differ to any material extent from those found in the water of Bentham Reservoir. Possibly, however, the water of Bentham Peat Pool approached nearer in [illegible] to the [illegible] of [illegible] germs than the water of Bentham Reservoir.

Next, as regards the bacteriological examination of Bentham (Burnmoor) peat soil.

Table XIII. shows the results of the bacteriological examination of the surface layer of Bentham peat soil for aerobic micro-organisms.

Here the average number of bacteria in the samples of peat [illegible] was 191,125 per gramme. [illegible] nevertheless equal [illegible] soils, and is even less than the number of microbes commonly found in most virgin soils.

As regards the kind of bacteria found in the cultures, it is to be noted that moulds and yeasts were usually present in abundance, and, unlike soils in general, B. Mycoides was only occasionally met with. The moulds and yeasts are doubtless derived from the atmosphere, and the reason why they flourish in peaty soil is probably due to the acidity of peat and its moist and nutritious character. Fluorescent bacteria and microbes belonging to the subtilis and mesentericus groups do not appear to be as numerous in peat as in soil obtained from other sources.

All the samples of peat were collected at different points on the Bentham (Burnmoor) gathering grounds, and all were taken from the surface layers.

But a number of experiments were also carried out with peat soil collected a *few inches below the surface*. The results obtained in this case are shown in Table XI., above.

It will be seen from the above table that eight samples of peat soil yielded on an average 39,063 bacteria per gramme. Thus, the number of microbes in peaty soil is distinctly less a few inches below the surface than immediately at the surface; the figures being 39,063 as compared with 101,153. Further, mould and yeast fungi are fewer in number in the deeper layers of peat soil.

A series of experiments was also carried out to determine the *number* of *anaerobic bacteria* in peaty soil, and Table XII. gives the results of the bacteriological examination of Bentham peat soil for anaerobic bacteria.

It will be seen on reference to this table that the average number of anaerobic microbes was 7,985 per gramme.

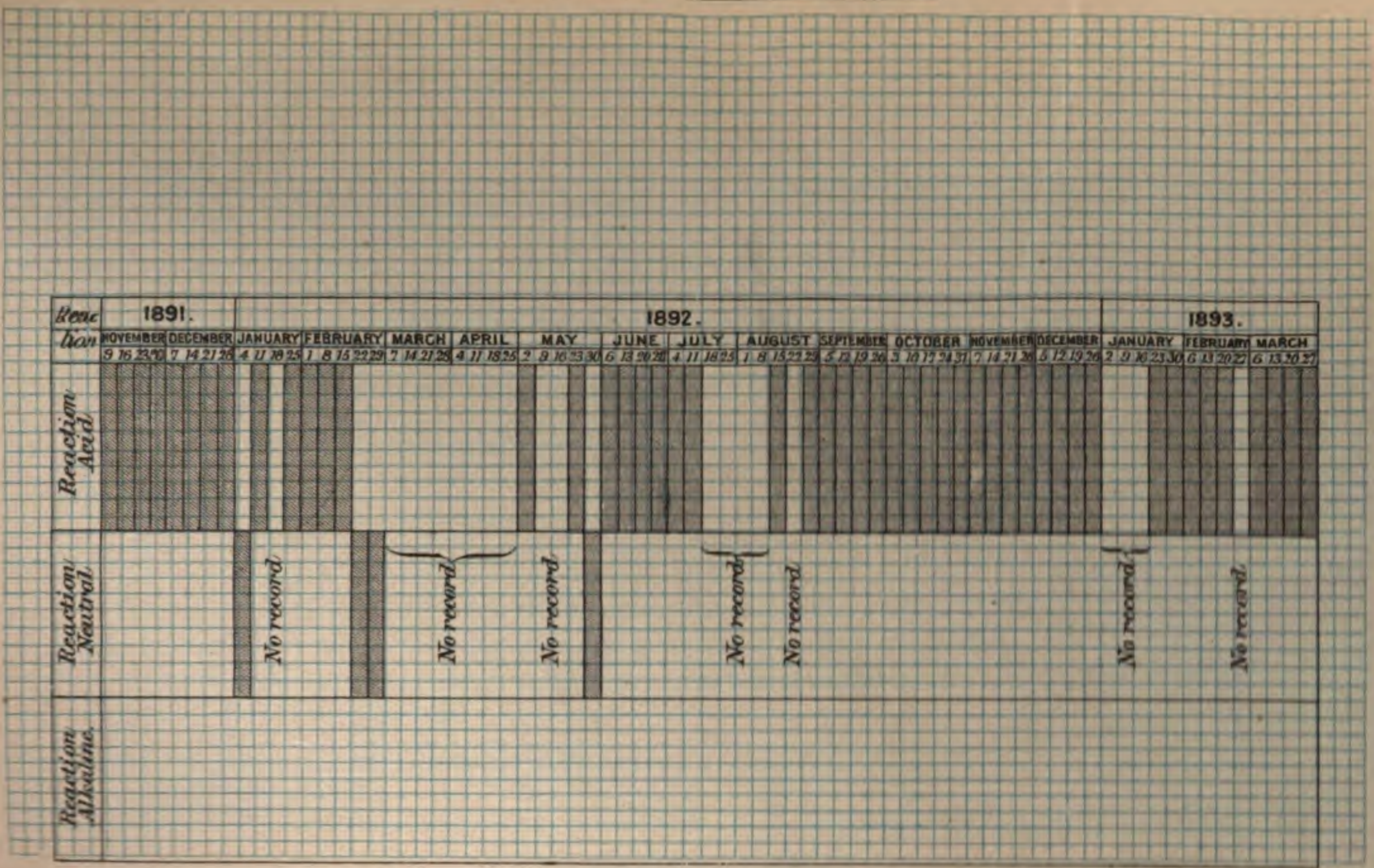
There did not seem to be any very great diversity of species among the anaerobic peat micro-organisms. Most of them appeared to be facultative anaerobes, and to grow most luxuriantly under aerobic conditions.

### ACIDITY OF PEAT SOIL IN RELATION TO BACTERIAL ACTION.

The surface of moist peat on the Bentham gathering ground was found to be invariably acid in reaction. The tests were made with blue litmus paper pressed against the peat, not with the fingers, but with a piece of stone, fragment of heath, or other object picked up from the gathering ground. These tests were made weekly for some months in 1893, each time at a number of different spots. Fresh places were chosen at each visit. At later dates the reaction of peaty surface soil had been tested by me frequently in course of my survey of different gathering grounds in Lancashire and Yorkshire, always with the same result. From this I came to conclude that although water is the vehicle which carries the acid substances to the waterworks, the antecedent cause of the acidity lies in processes taking place in the peat itself. This led to a considerable amount of work in determining the part played by bacteria in the production of acid in peat. The results have been given in outline by Mr. Power in his memorandum in the Report of the Medical Officer of the Board for 1893–4, and the details will be given in a subsequent report. Here, however, for the sake of completeness it will be well to refer to a few of the results.

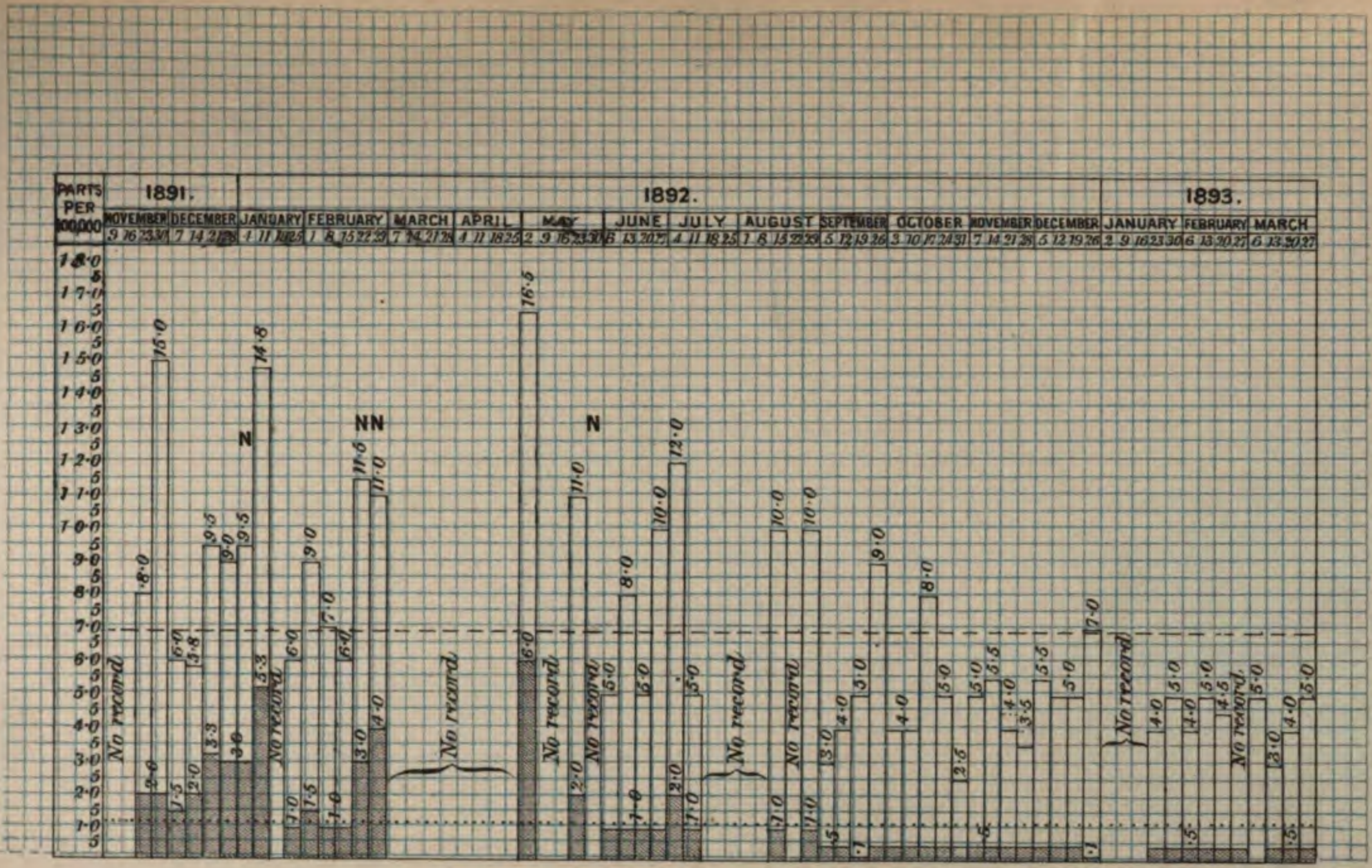
Peat brought into contact with neutral rain and distilled water, in such a way as to simulate the stagnation of rain in depressions of peat, and the percolation of rain-water through peaty soil, invariably conferred acid properties and plumbo-solvent ability upon the water. Acid peaty water obtained from moorland gathering grounds and stored in bottles under varying conditions never showed an increase in acidity, but rather an appreciable decrease. Such water neutralized before being stored in bottle never recovered acidity. Hence it may be concluded that moorland water when separated from peat has completed its history so far as production of acid is concerned. Then as regards the production of acid in the peat itself. A mixture of peat bacteria, when grown in neutral sterile decoction made solely from peat, rendered the liquid acid and plumbo-solvent. When the experiment was repeated with certain individual species of peat bacteria in pure cultivation, the result was in nearly all cases otherwise—the decoction remained neutral and had no action upon lead. Two microbes, however (provisionally termed peat bacteria O and Q in Mr. Power's Memorandum) yielded positive results. Each had the power, when grown in a neutral peat decoction, of rendering the liquid acid and conferring on it ability to dissolve lead. The net result of the experiments has thus been to afford presumptive evidence of the strongest kind that the antecedent cause of the acidity and plumbo-solvent ability of a moorland water is the vital action of particular species of bacteria in moist peat soil.

SHOWING THE RESULTS AS REGARDS REACTION OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM PEAT POOL.



Wyman & Sons, Ltd, Lith. 7781-12-95.

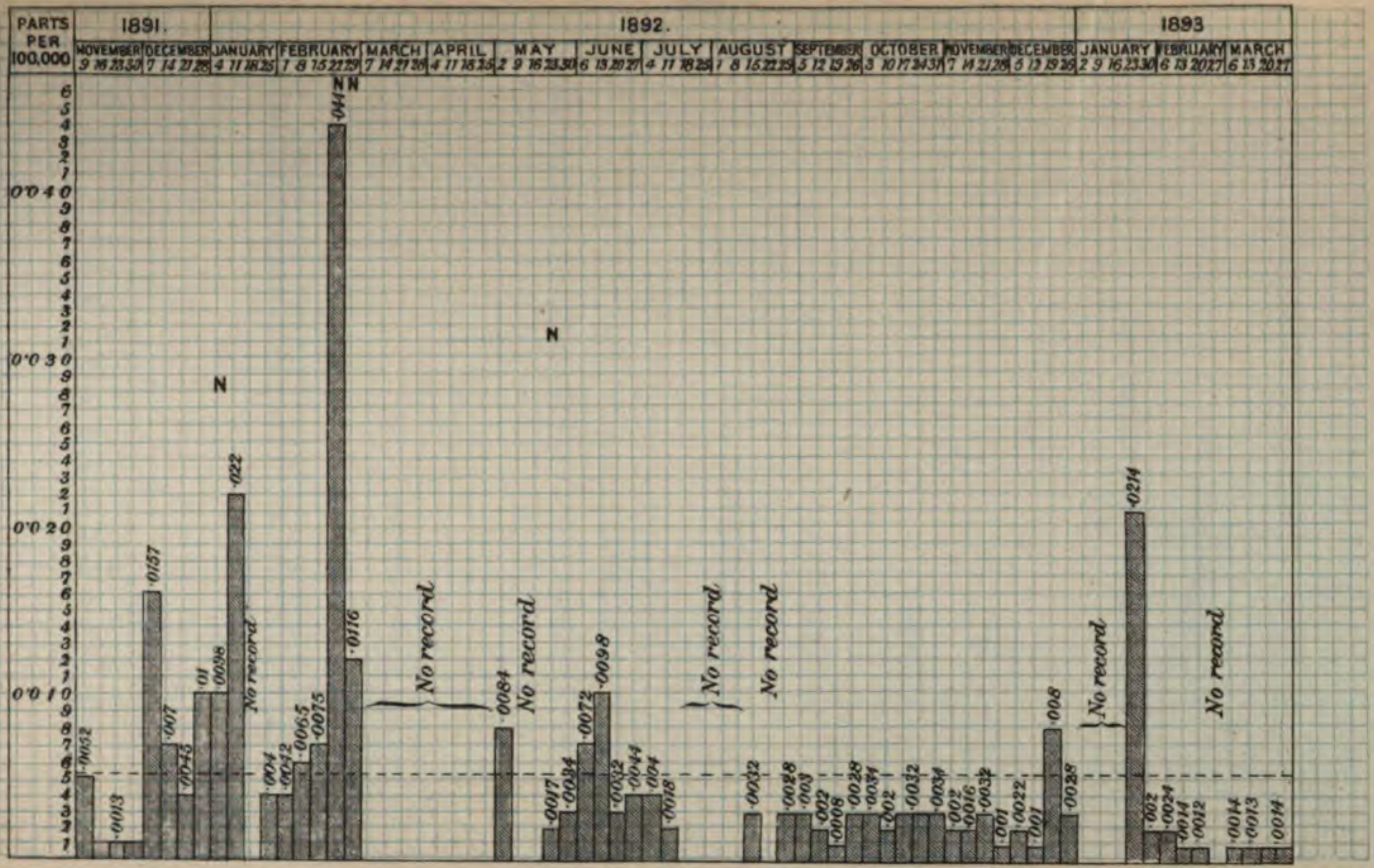
OF THE WATER OF DENTHAM PEAT POOL.



Wyman & Sons, Ltd., Lith. 7791-12-95.

N = *Neutral Reaction.*

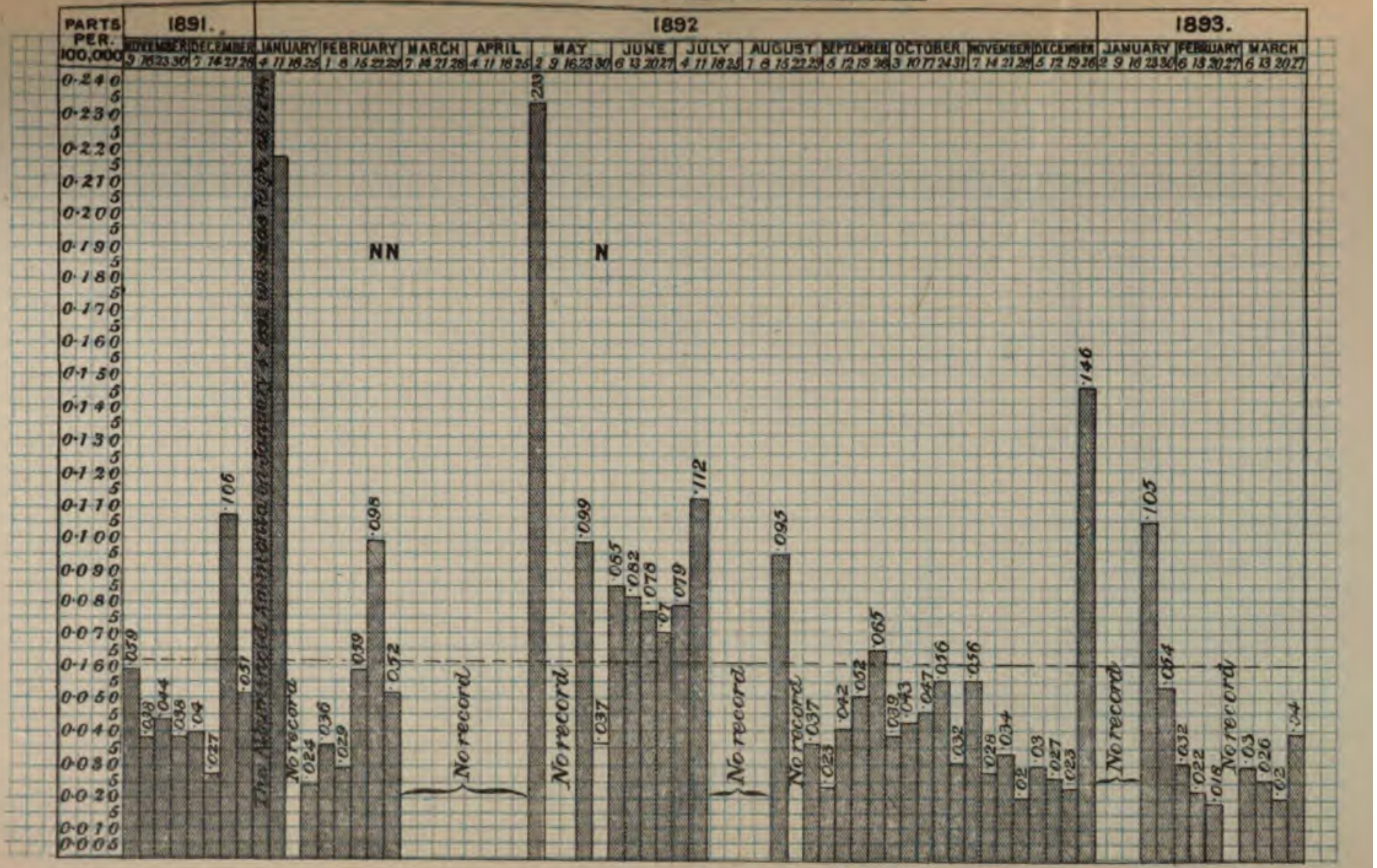
*The total height of the columns represents the total solids: the shaded columns*



N = *Neutral Reaction.*

Wyman & Sons, Ltd, Lith, 7540-12-95.

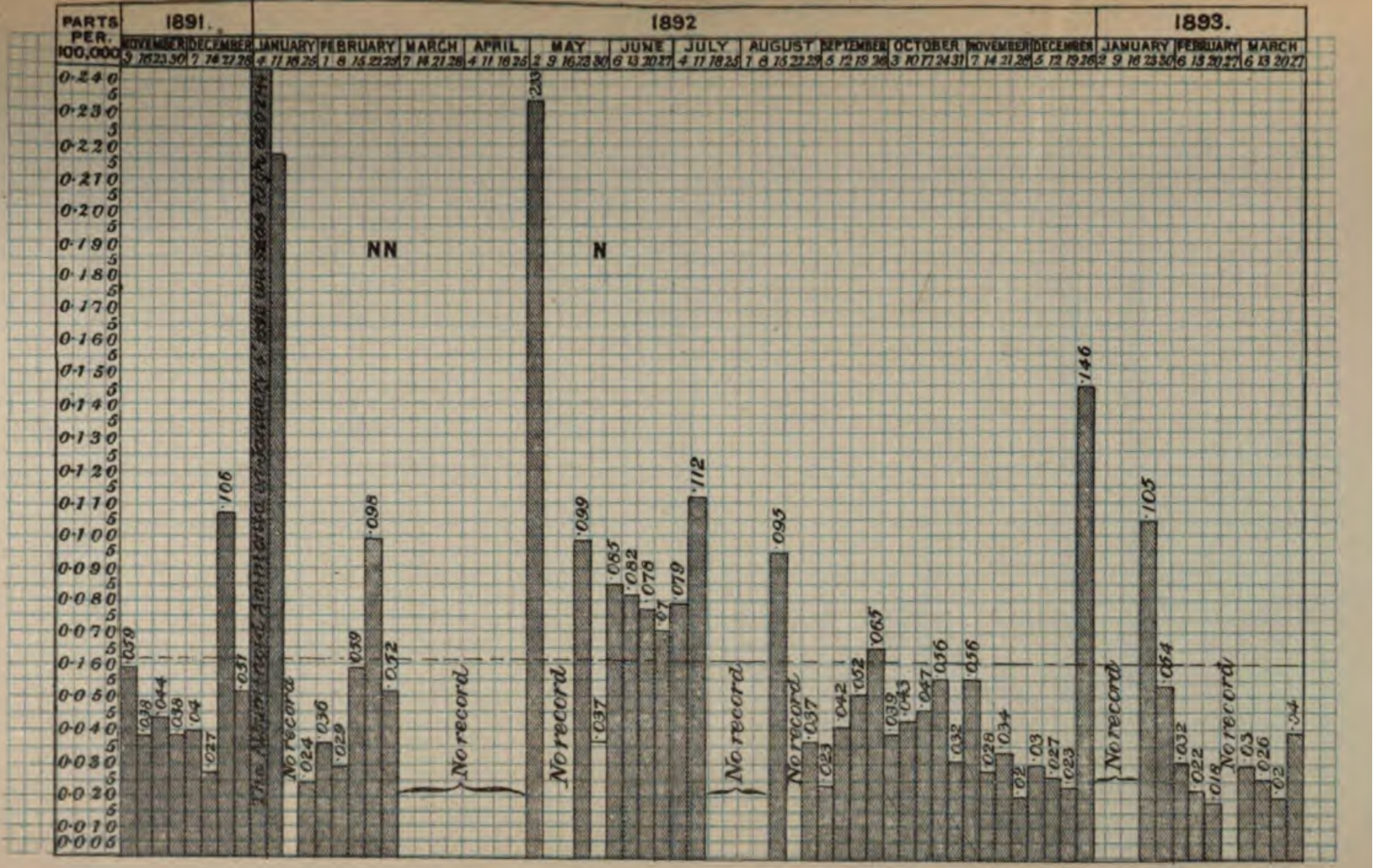
OF THE WATER OF BENTHAM PEAT POOL.



N = Neutral Reaction.

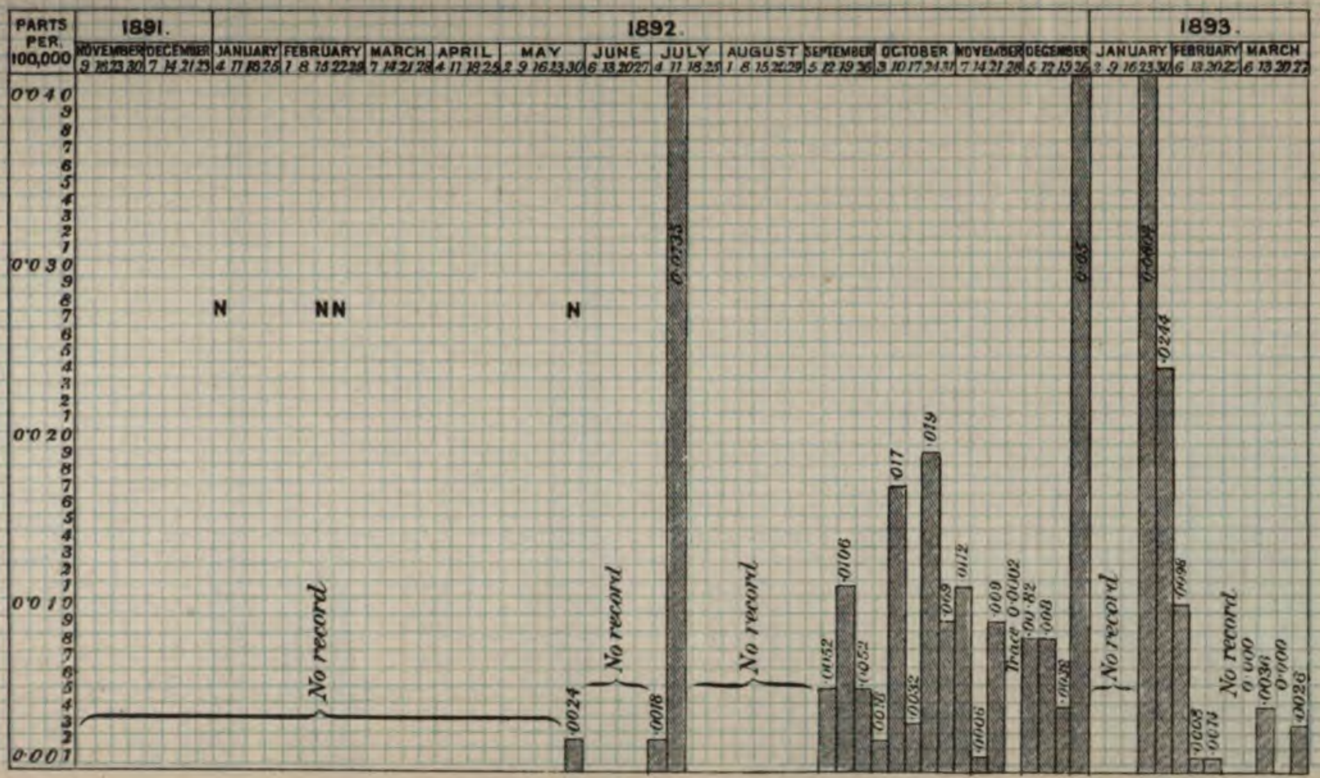
Wyman & Sons, Lᵈ. Lith 7540 17 95

OF THE WATER OF BENTHAM PEAT POOL.



N = Neutral Reaction.

Wyman & Sons, Ld., Lith 7540·17·95



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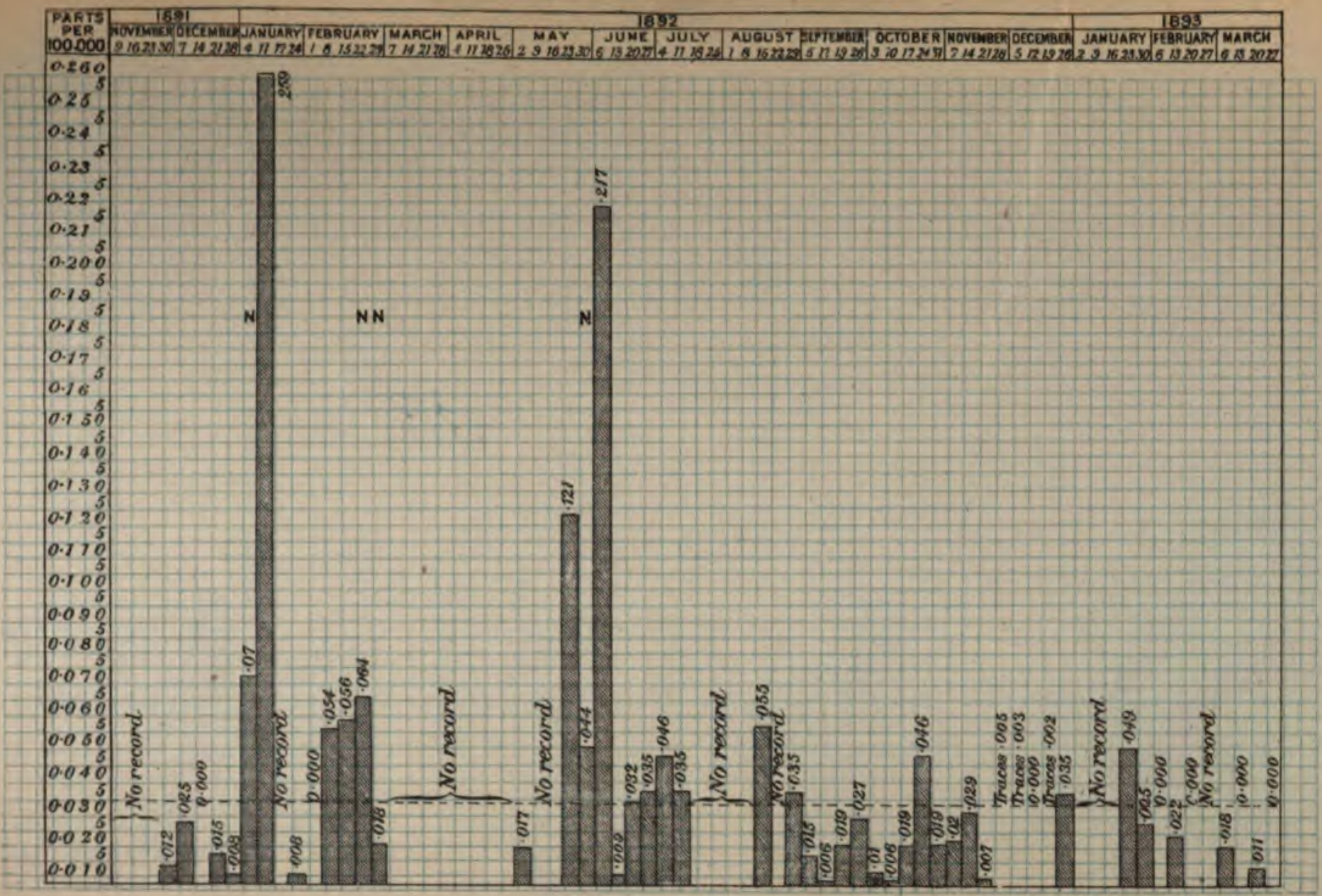
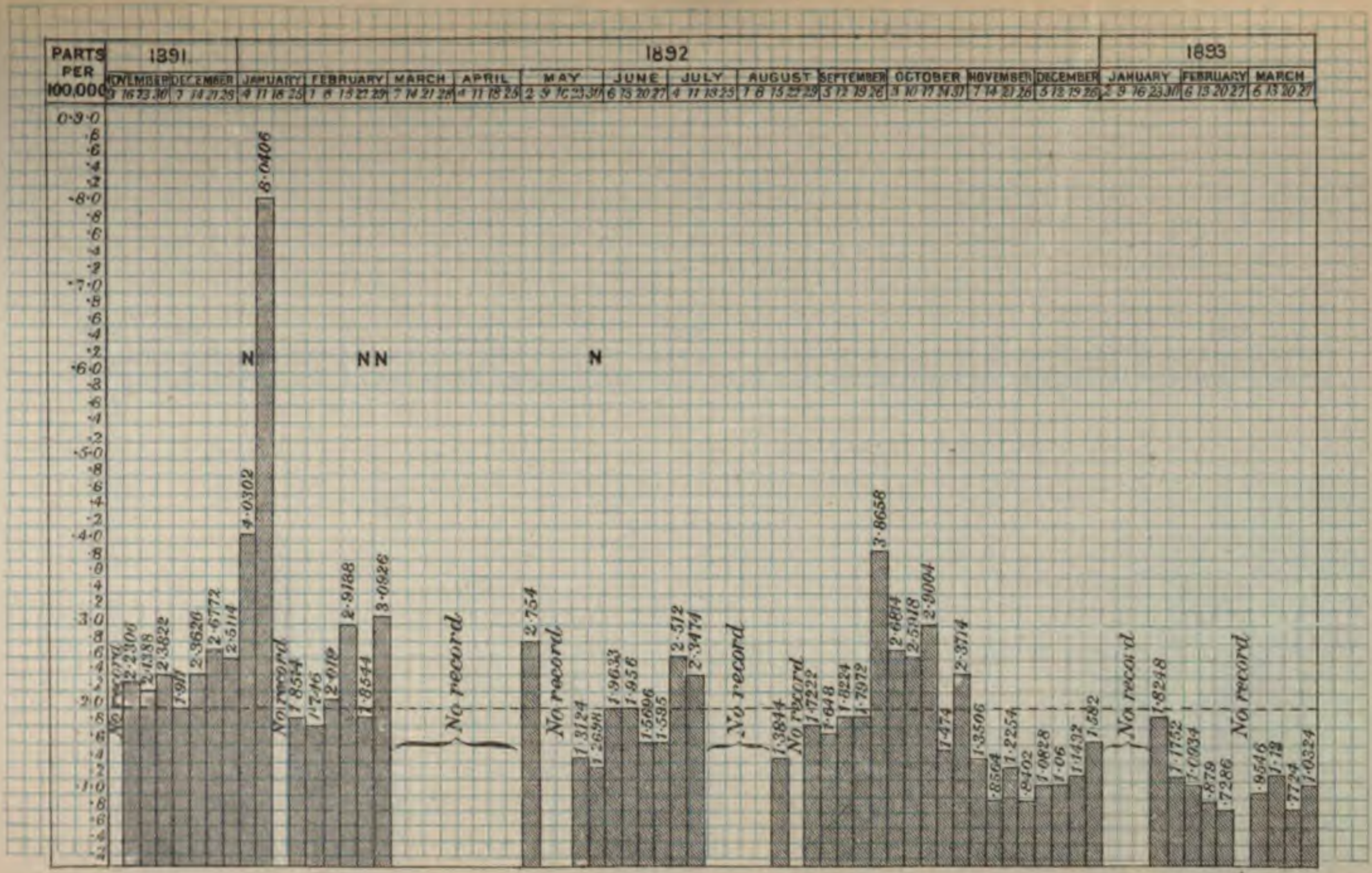
Wyman & Sons Ltd. Lith. 7540·12·95.

## OF THE WATER OF BENTHAM PEAT POOL.



N = *Neutral Reaction.*

Wyman & Sons, Ltd, Lith 7540·12·93



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Wyman & Sons, Ltd, Lith 7540·12·95

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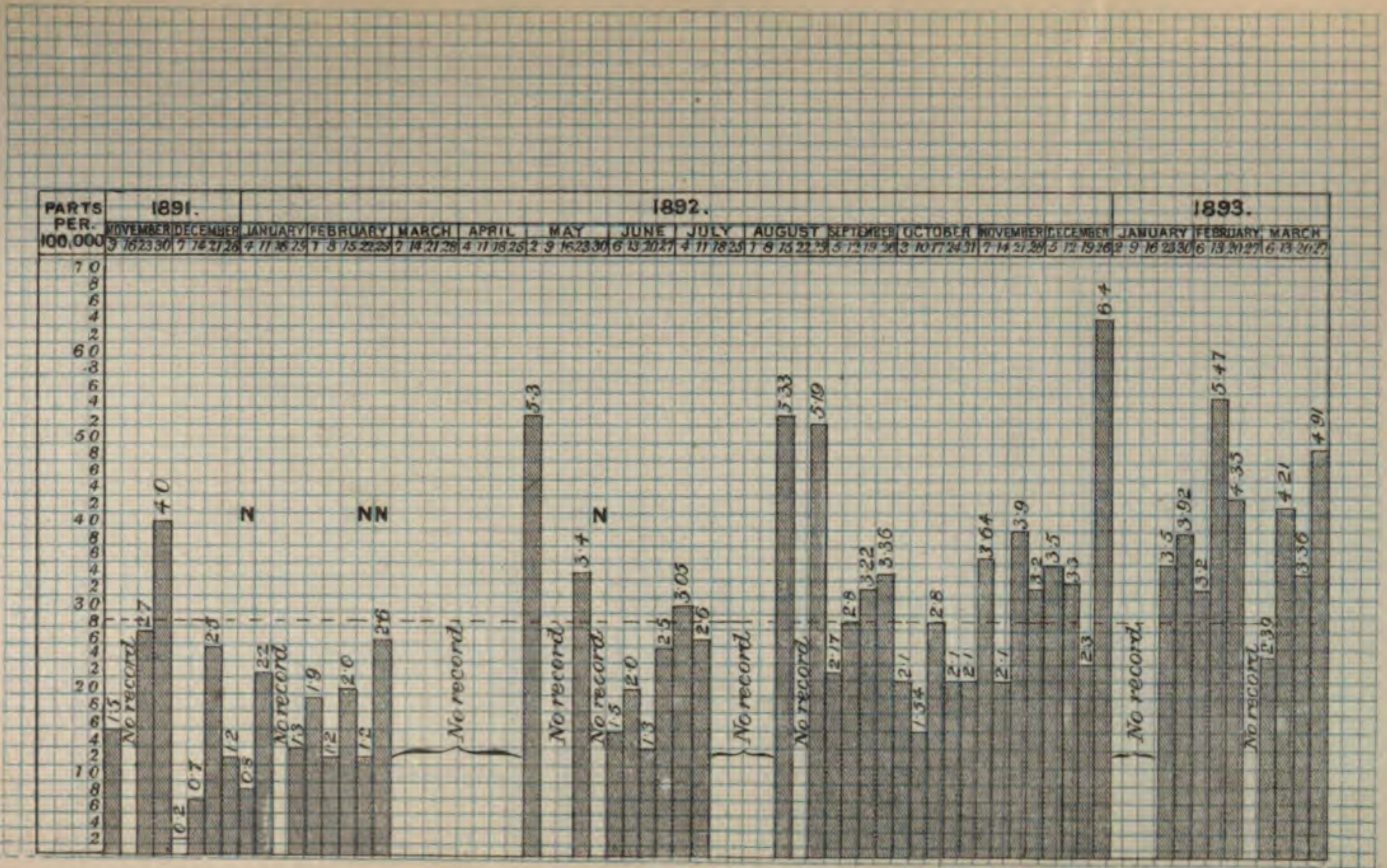
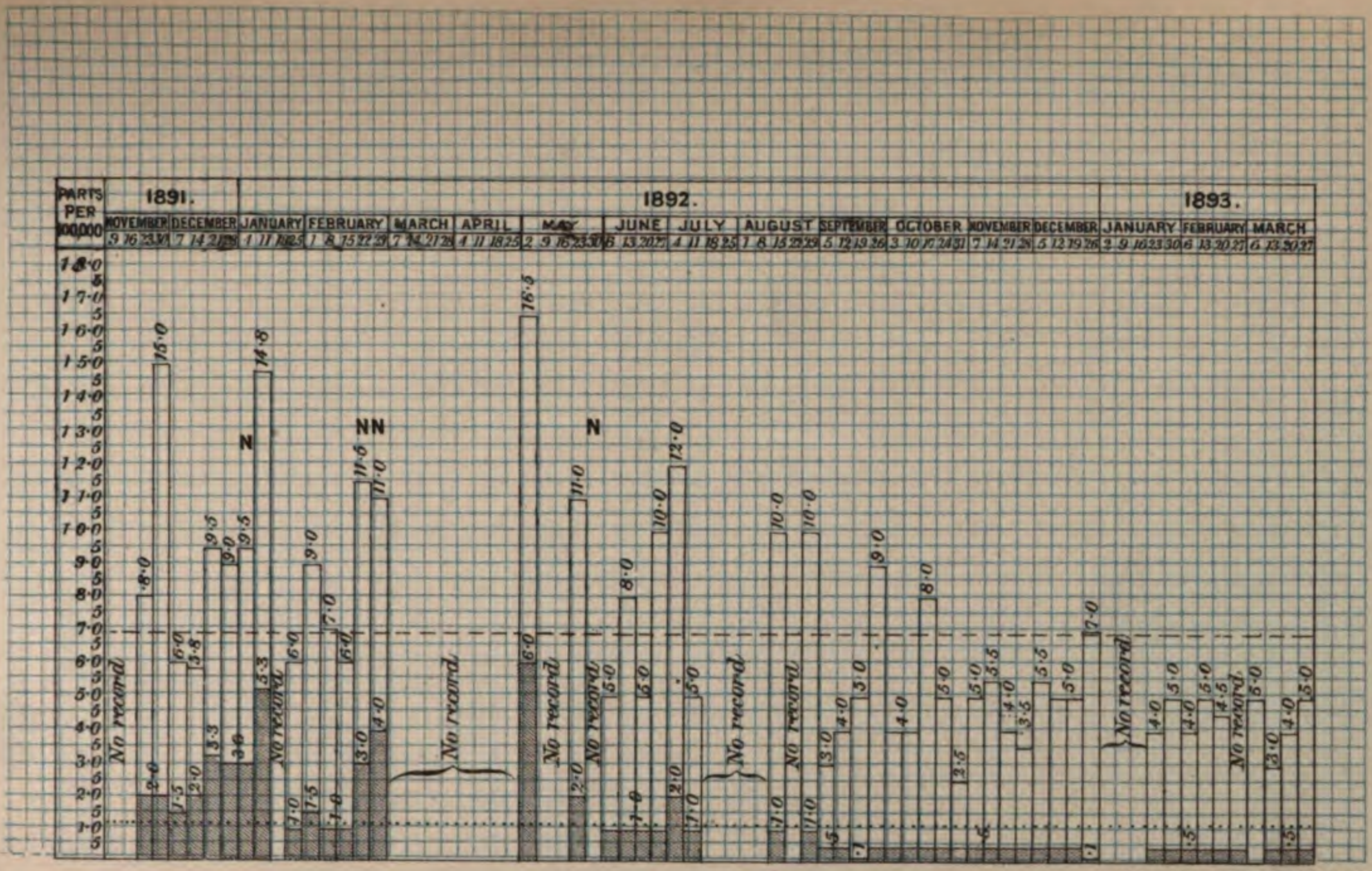


N = *Neutral Reaction.*

Wyman & Sons, Lᵈ, Lith. 7540·12·93.

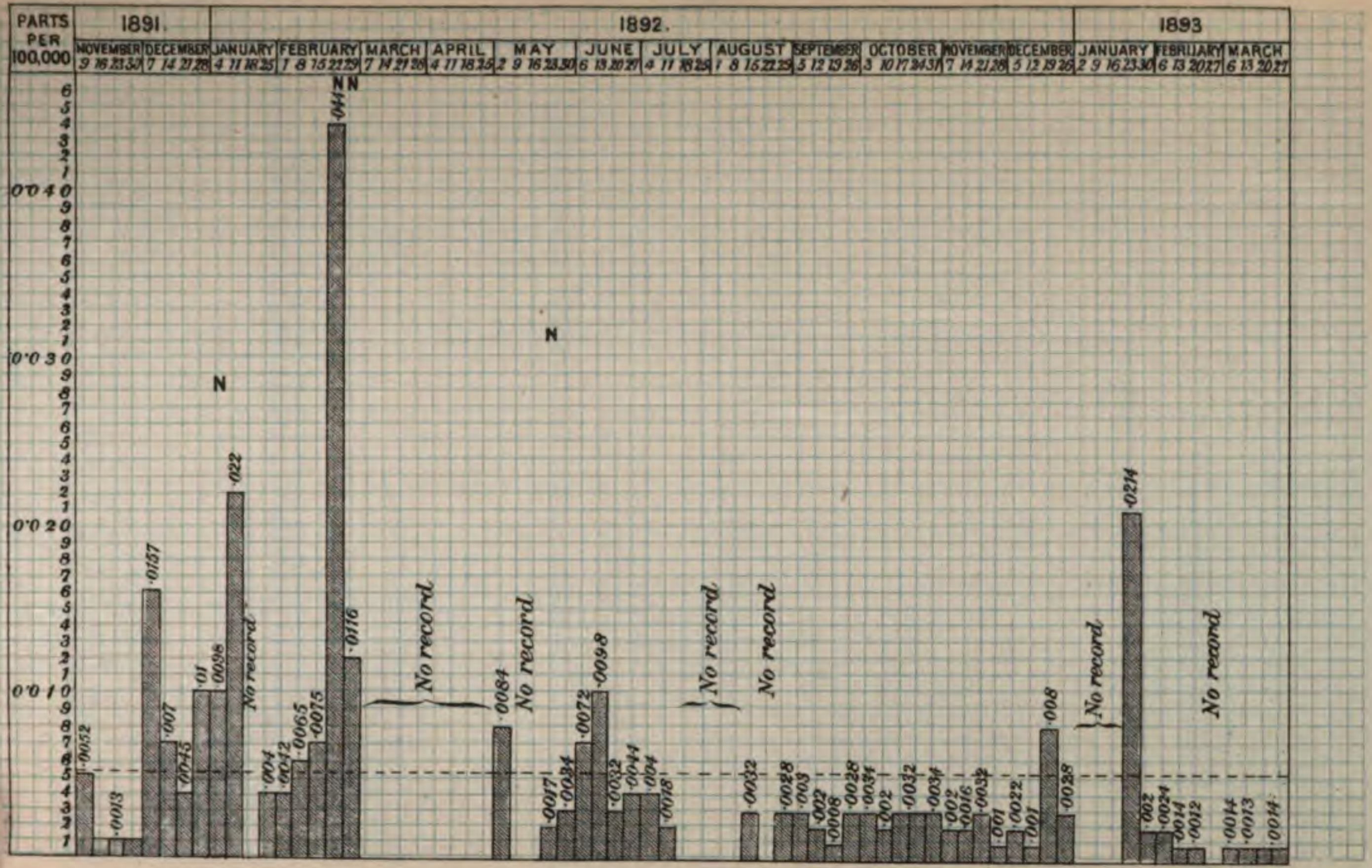
OF THE WATER OF BENTHAM PEAT POOL.



Wyman & Sons, Lᵗᵈ, Lith, 7791-12-95.

N = Neutral Reaction.

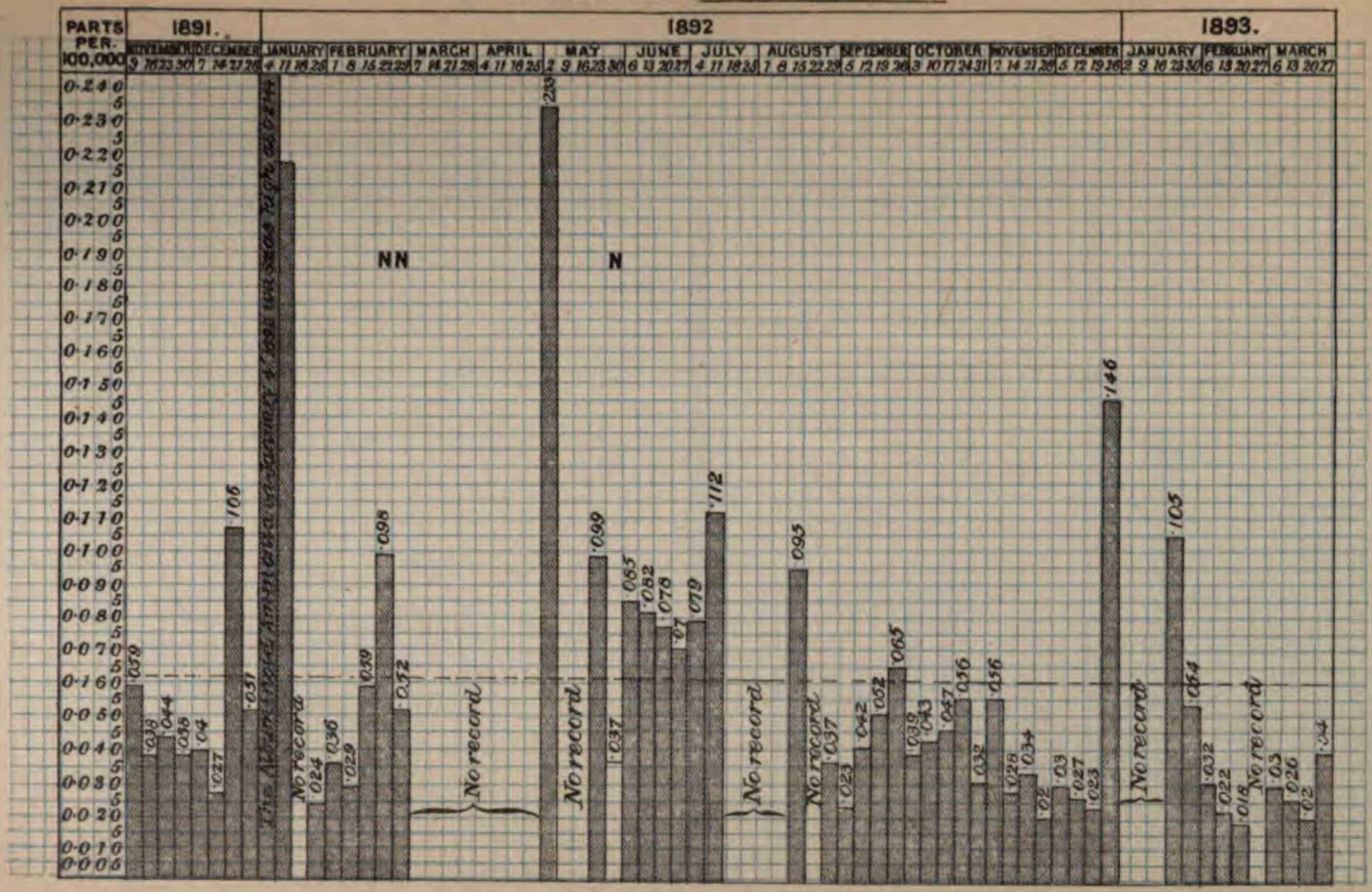
*The total height of the columns represents the total solids: the shaded columns refer to the fixed solids & the difference between these two shows the volatile solids.*



N = *Neutral Reaction.*

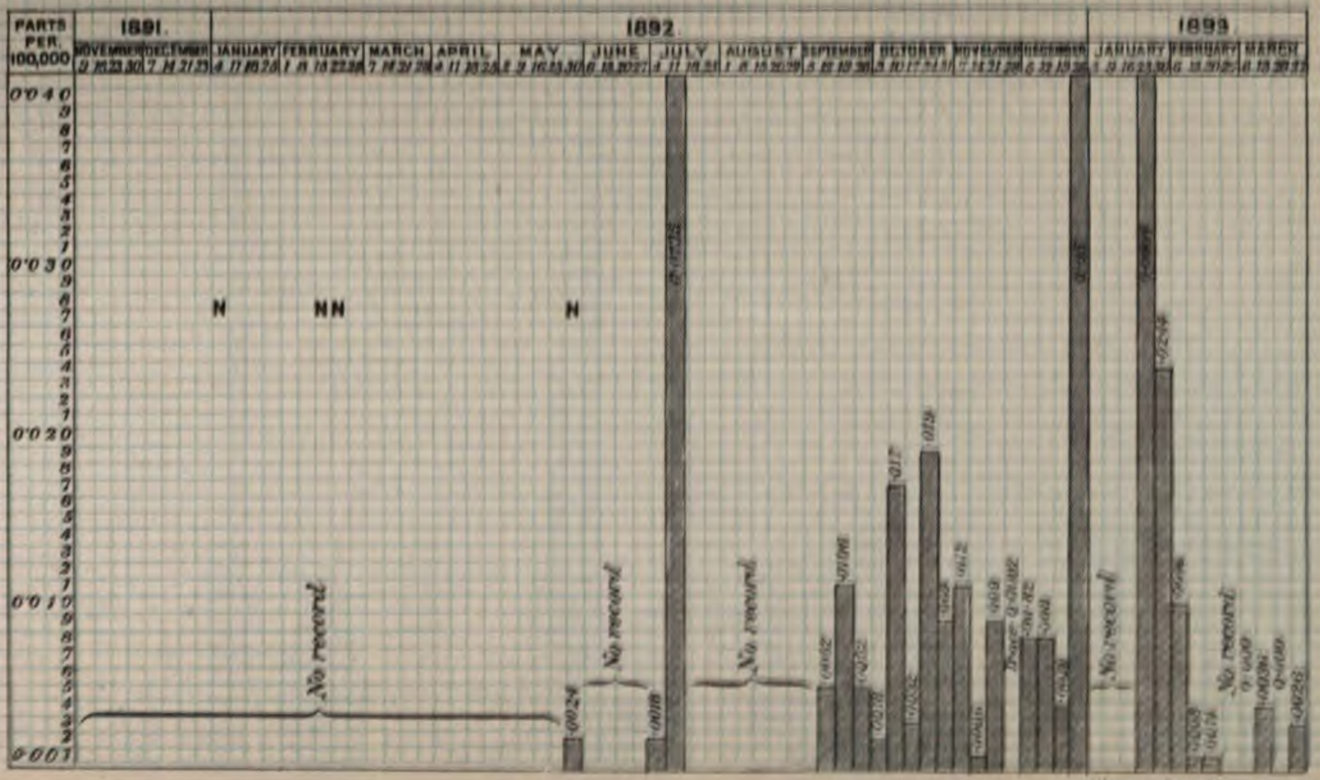
Wyman & Sons, Ltd, Lith, 7540·12·95.

OF THE WATER OF BENTHAM PEAT POOL.



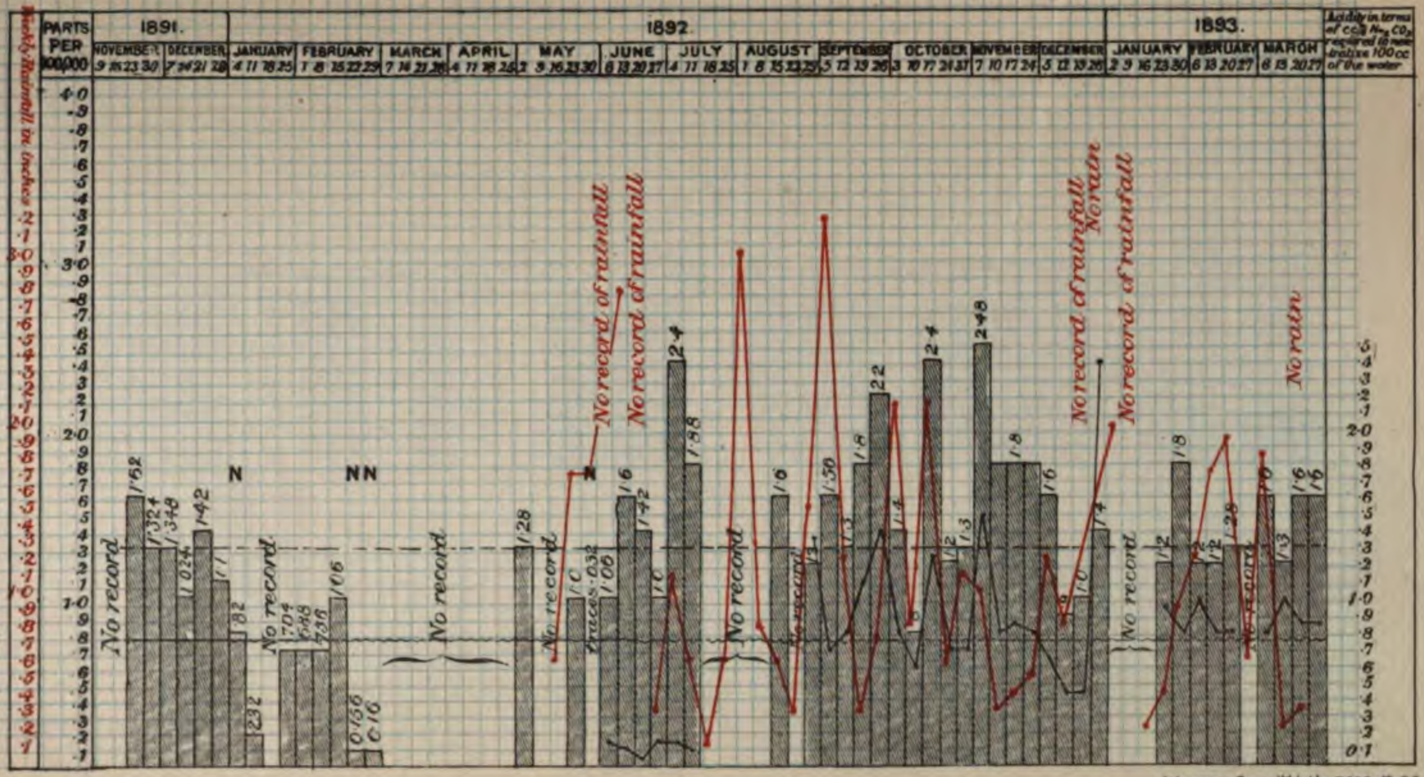
N = *Neutral Reaction.*

Wyman & Sons, Ltd, Lith 7540 12 95



N-Neutral Reaction.

Wyman & Sons Ld Lith. 1140·12·93

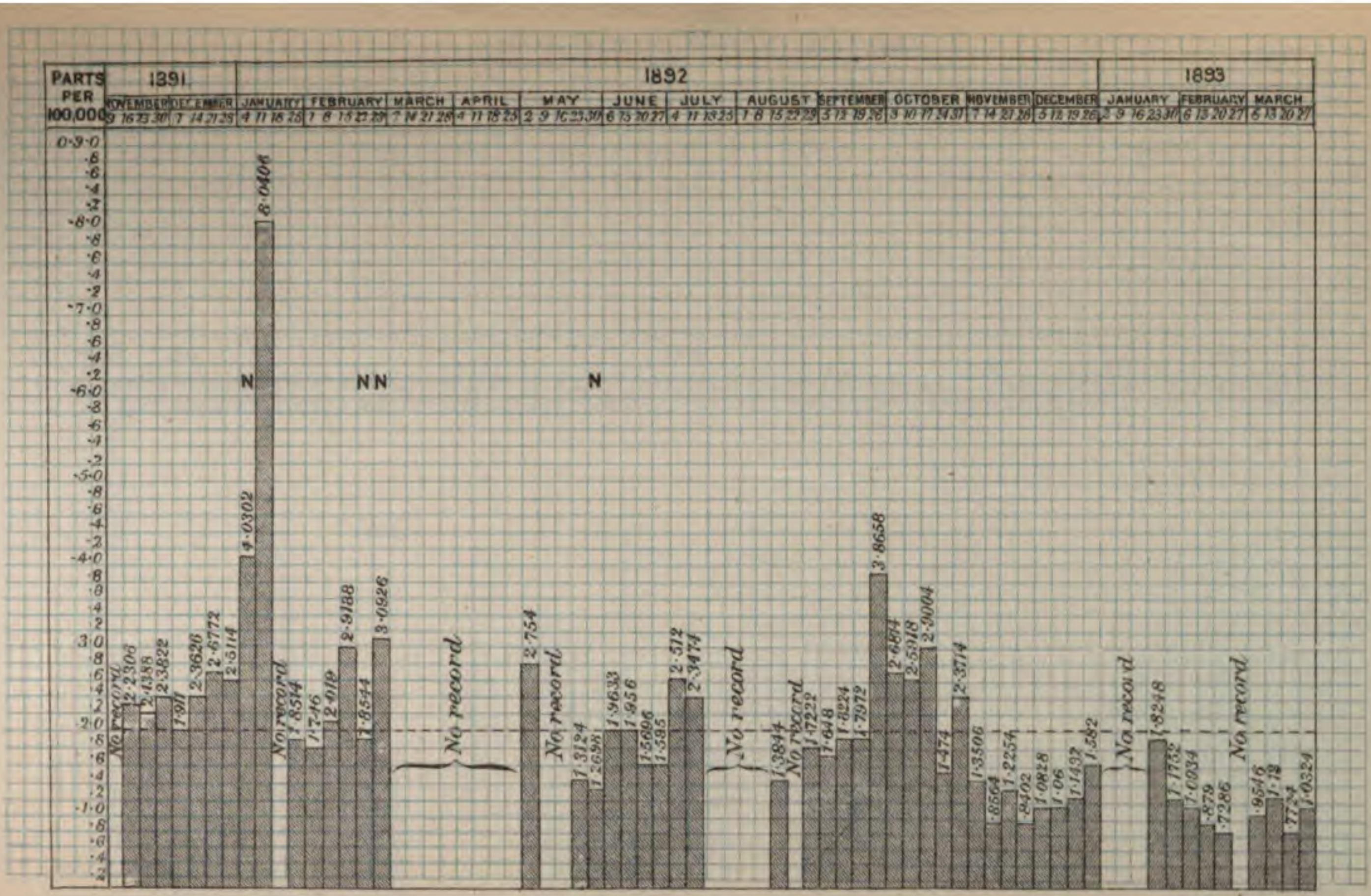


Wyman & Sons, Ld., Lith, 7540·12·95.

N = Neutral Reaction

*The shaded columns refer to the plumbo-solvency, the dotted black line refers to the acidity & the dotted red line to the rainfall.*

*- - - - - = average plumbo-solvency. ~~~~~~ = average acidity.*

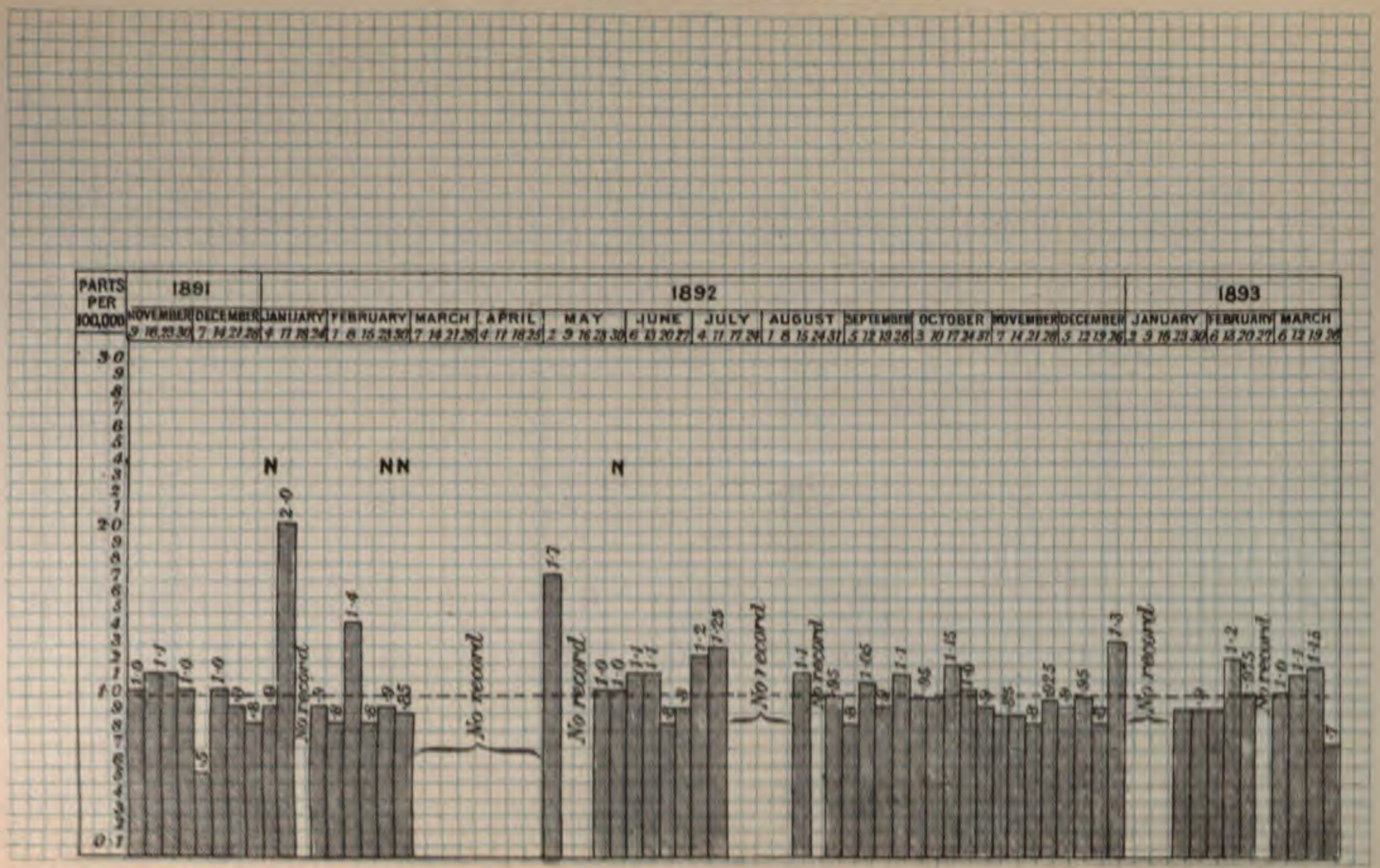


N = *Neutral Reaction*

Wyman & Sims, Ltd, Lith 7540·12·95

# DIAGRAM 8

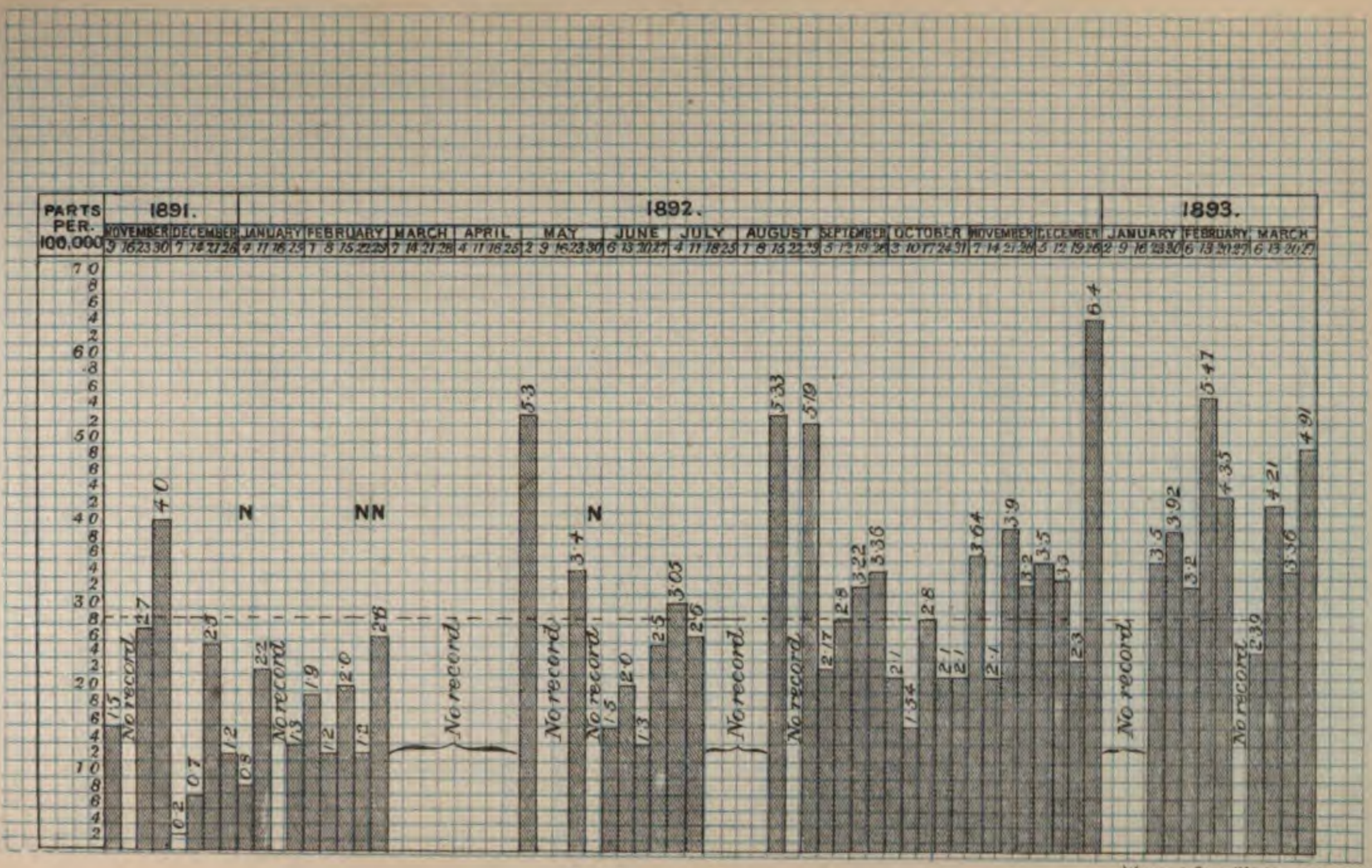
SHOWING THE RESULTS AS REGARDS CHLORINE, OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM PEAT POOL.



N = Neutral Reaction.

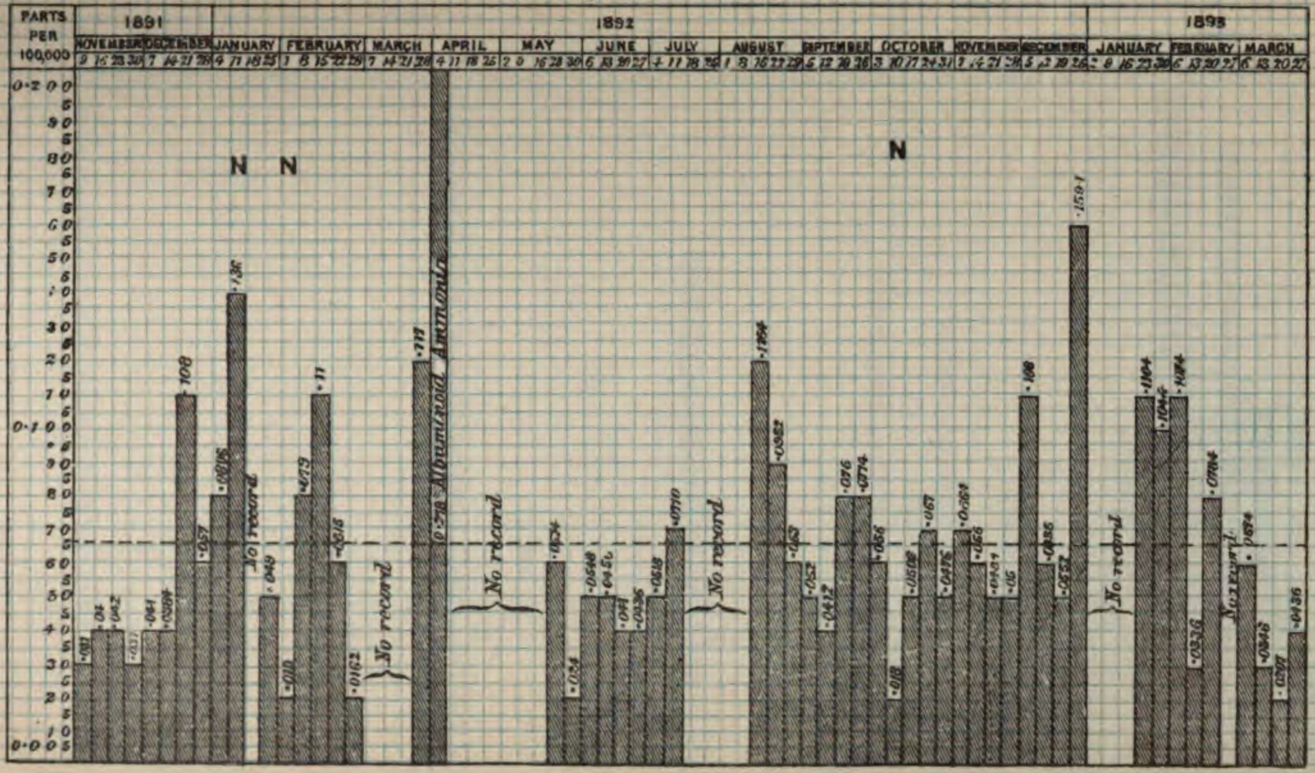
Wyman & Sons, Ld Lith. 7640 · 12 · 93.

OF THE WATER OF BENTHAM PEAT POOL.



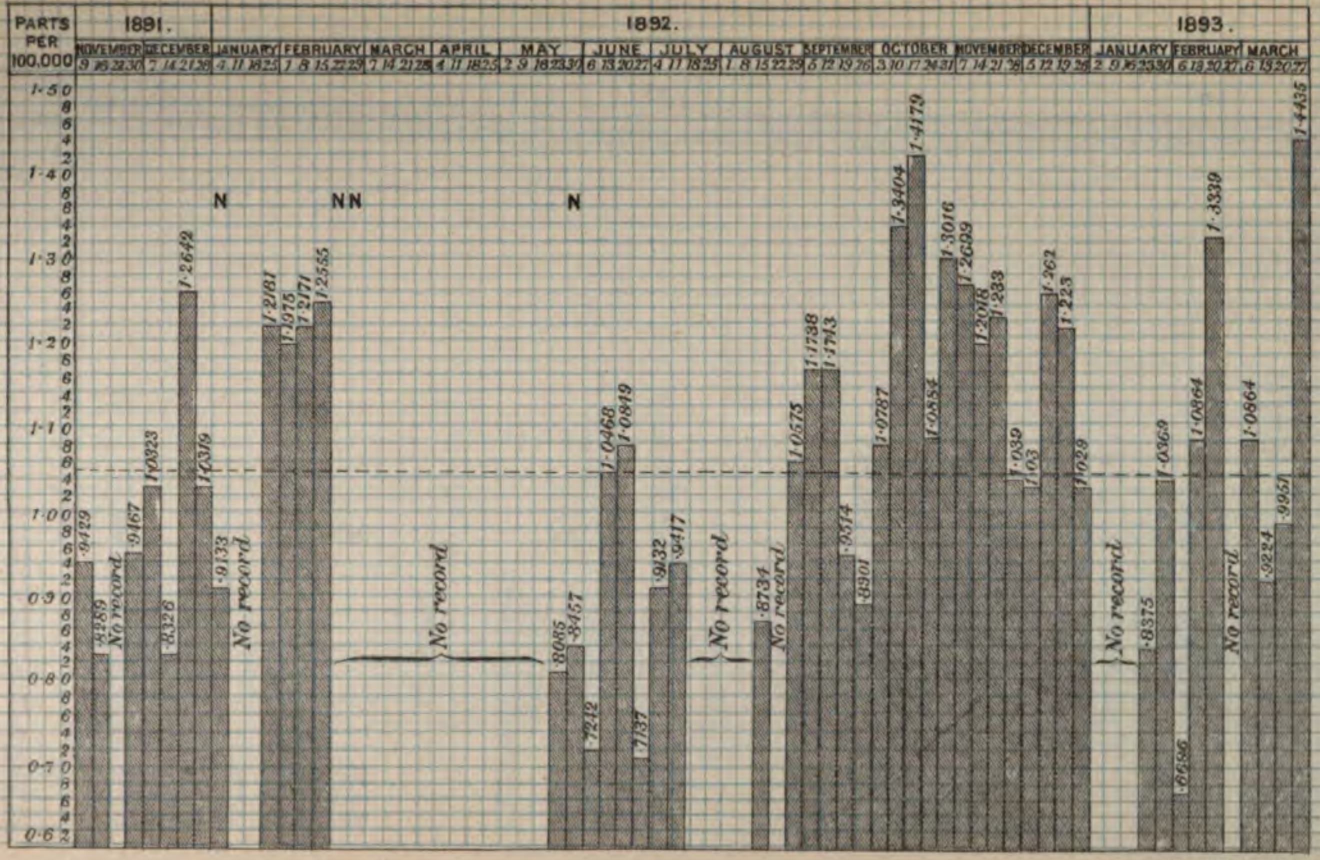
N = *Neutral Reaction.*

Wyman & Sons, Ltd, Lith, 7540·12·93.



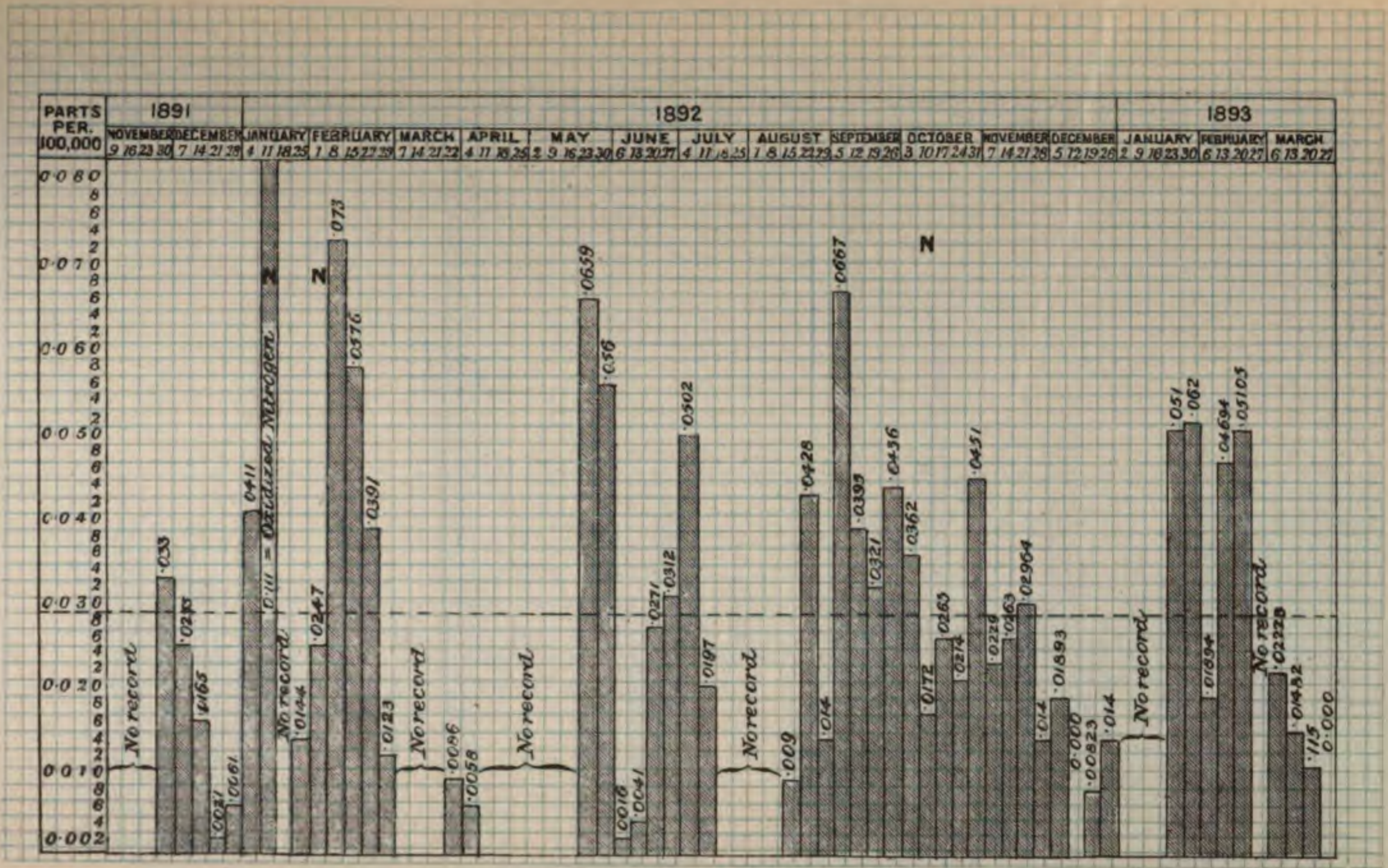
N=*Neutral Reaction.*

Wyman & Sons Ltd, Lith 7540 12 95



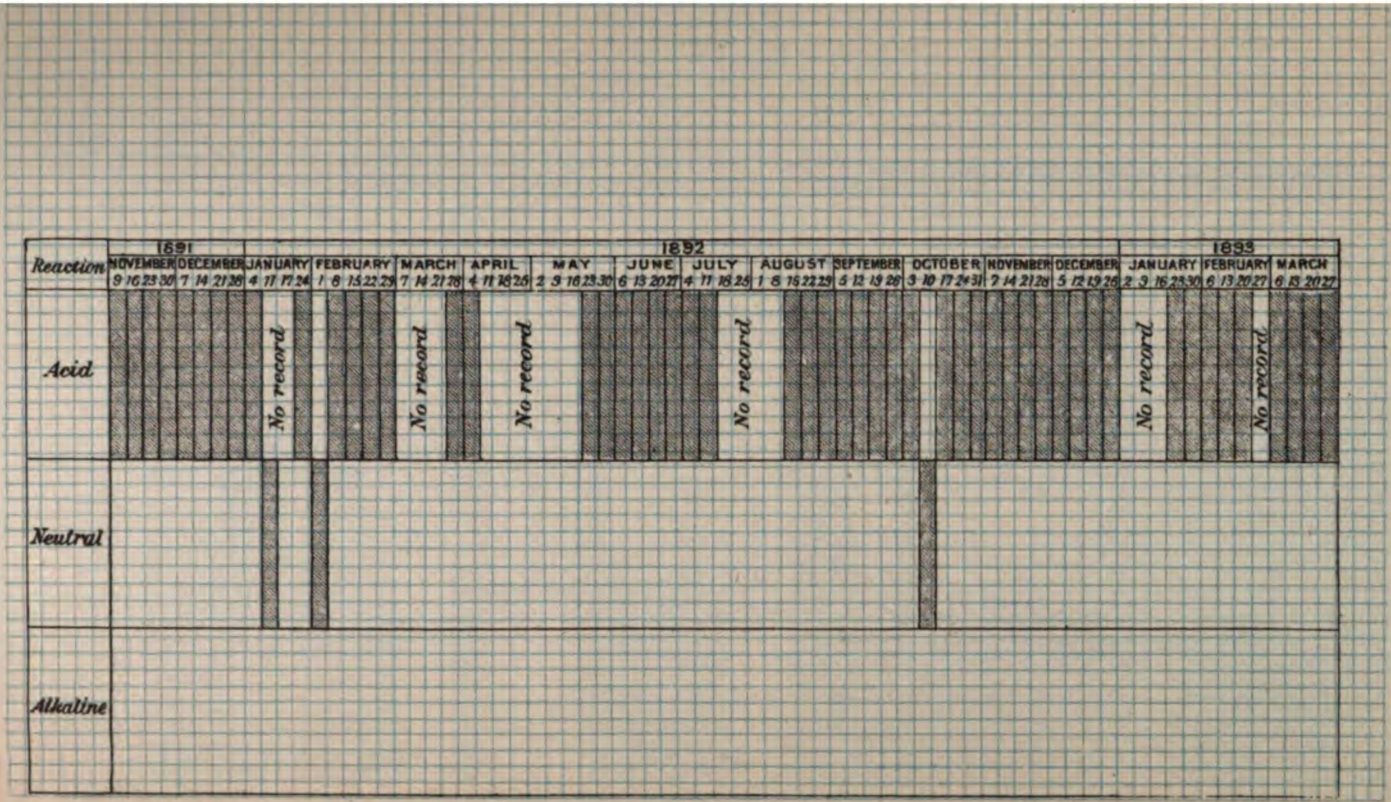
Wyman & Sons, Ltd, Lith, 7540·12·35.

N = Neutral Reaction.



N-Neutral Reaction.

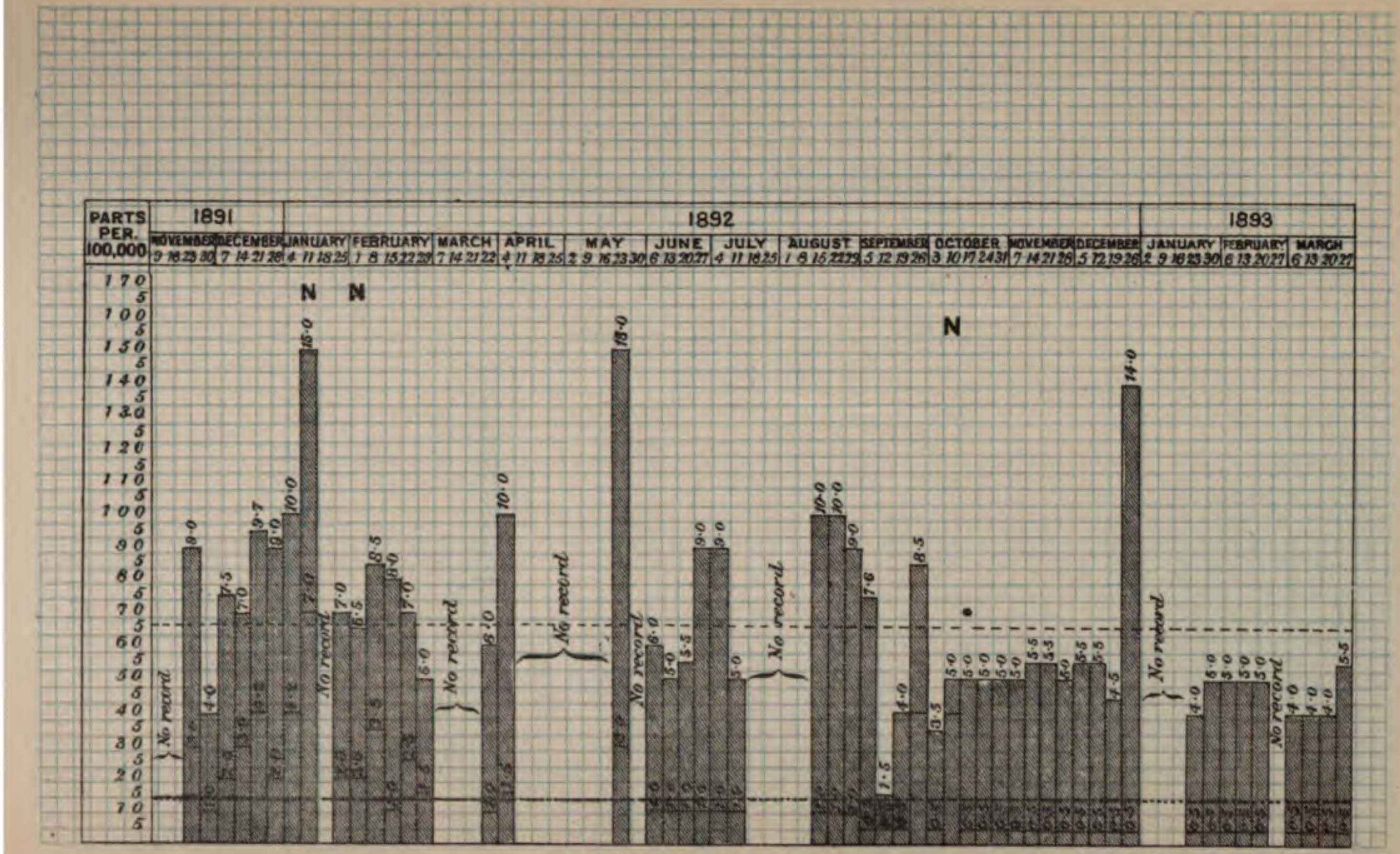
Wyman & Sons, Ld, Lith. 7540·12·95.



Wyman & Sons, Ld, Lith, 7540-12-95

## DIAGRAM IV.

SHOWING THE RESULTS AS REGARDS TOTAL FIXED & VOLATILE SOLIDS OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM MOSS POOL.

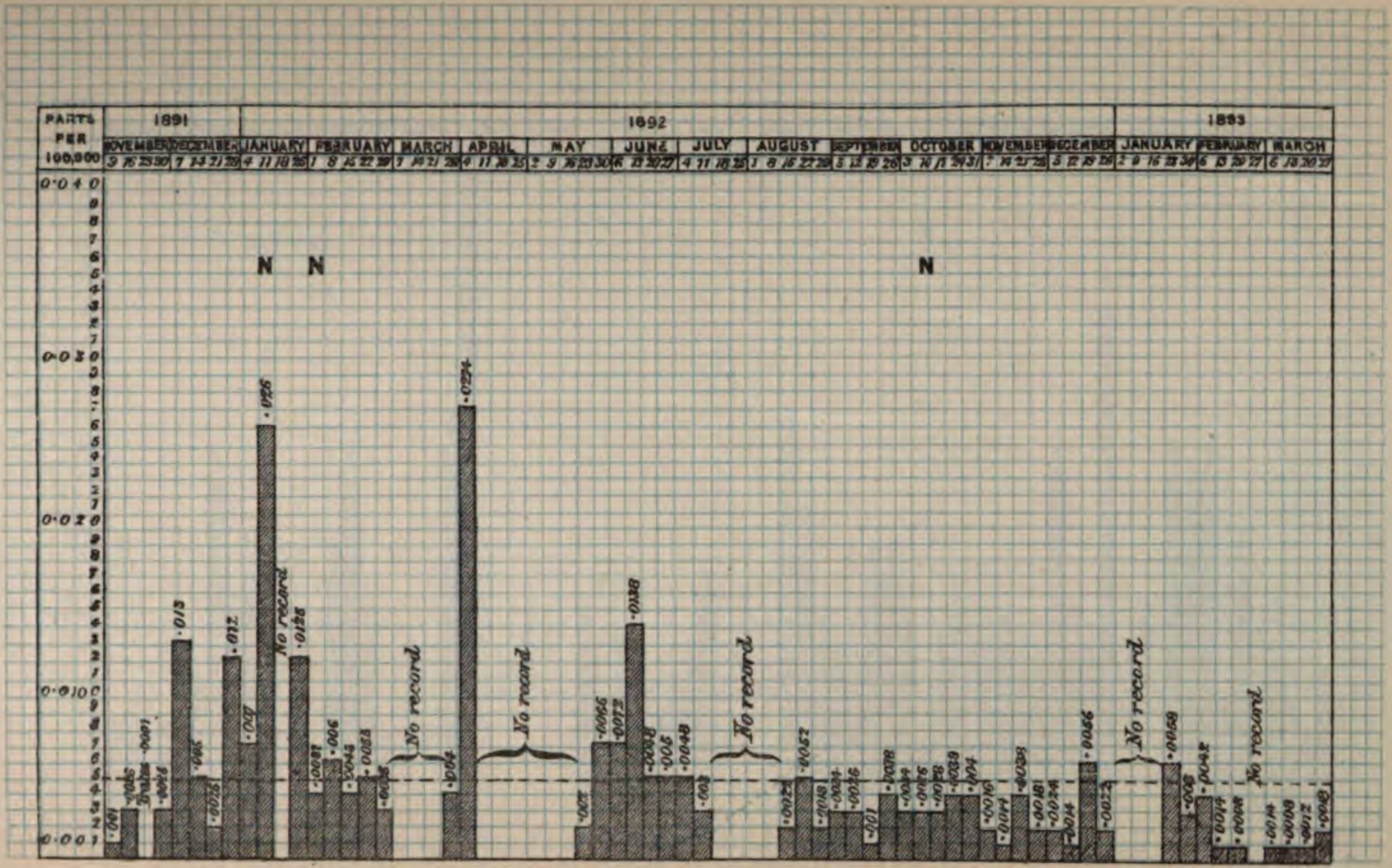


N = *Neutral Reaction.*

Wyman & Sons, Lᵈ, Lith 7540·12·95

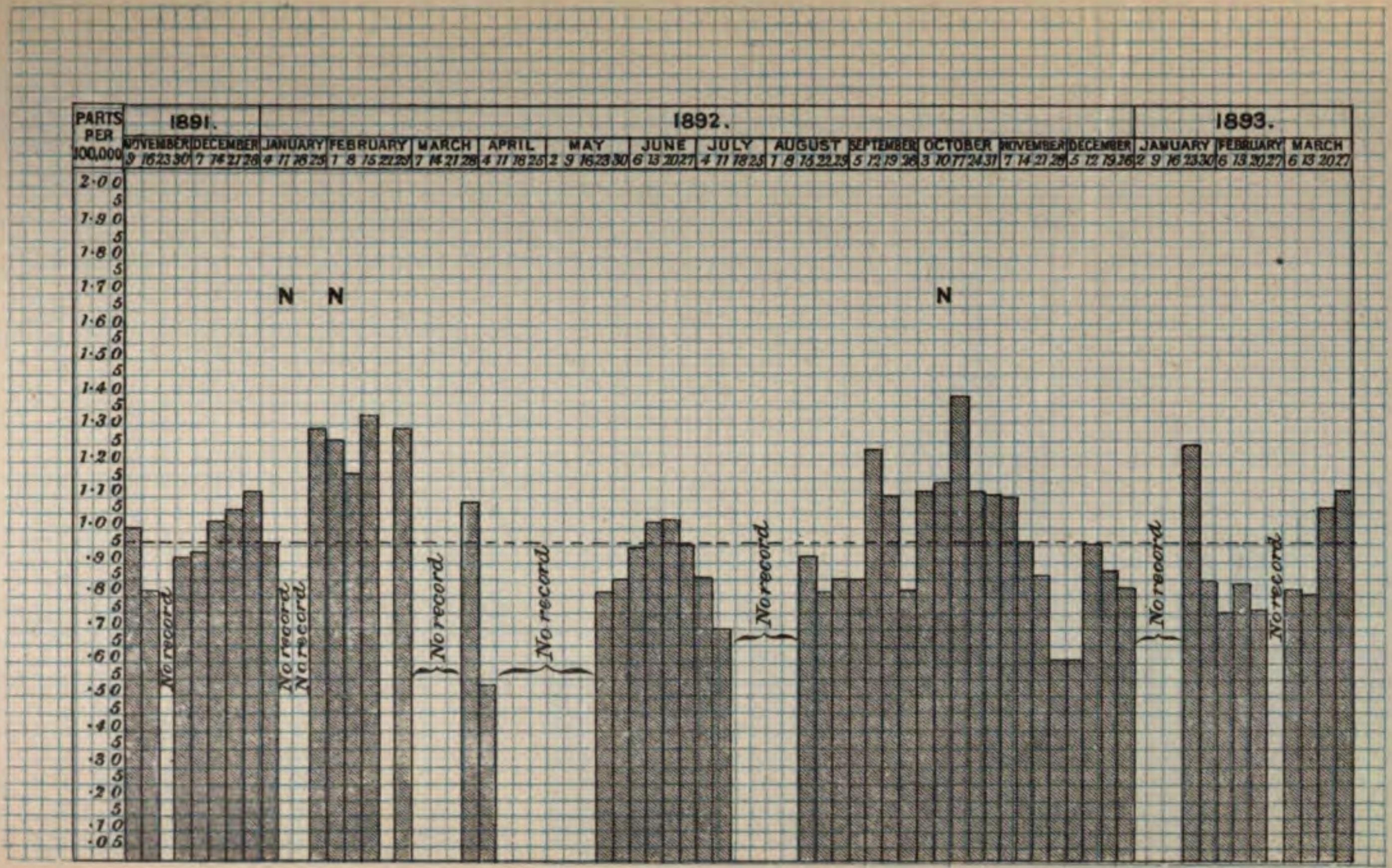
# DIAGRAM 15.

SHOWING THE RESULTS AS REGARDS FREE AMMONIA OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM MOSS POOL



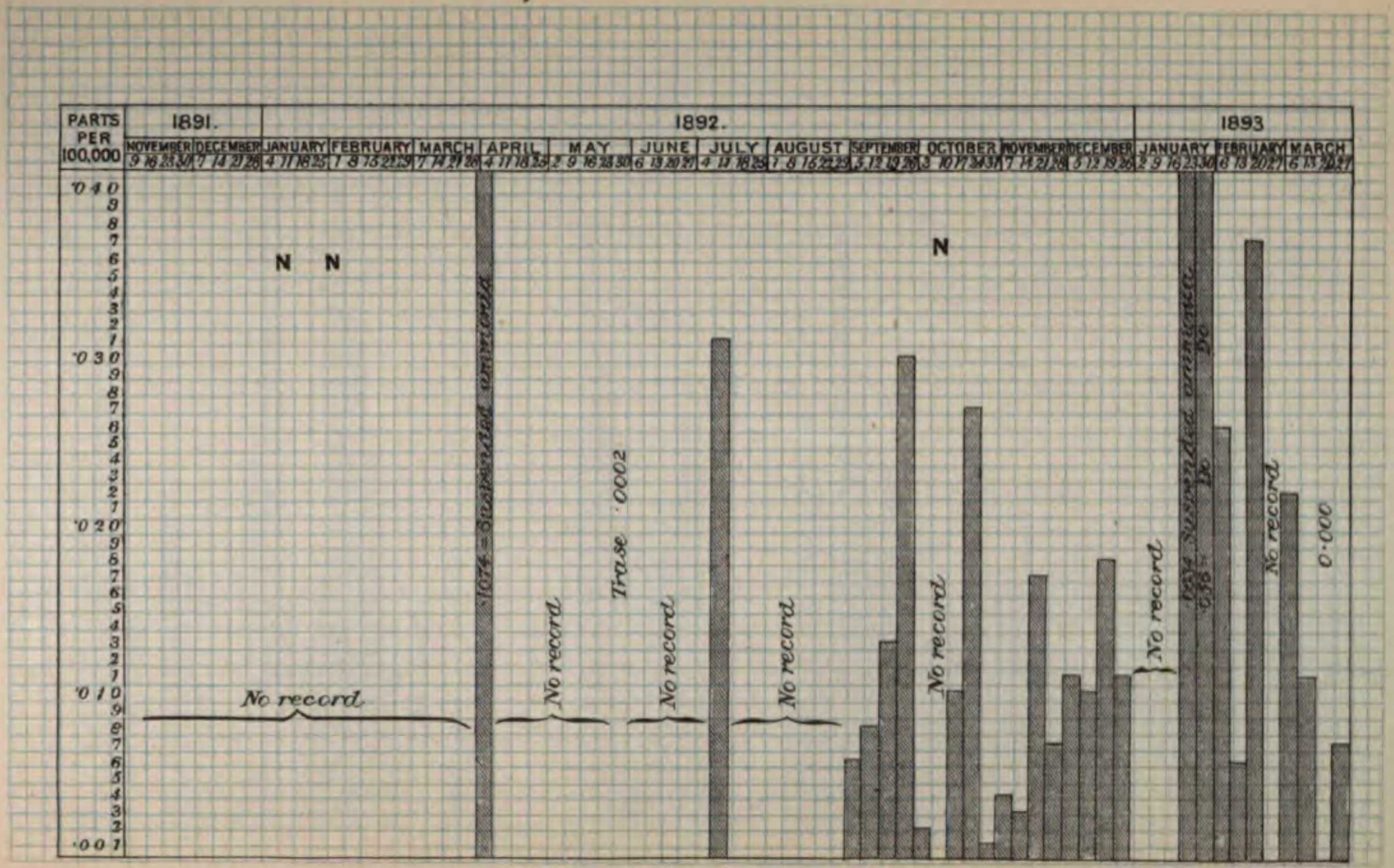
N = Neutral Reaction.

Wyman & Sons, Ld. Lith 7540·12·95.



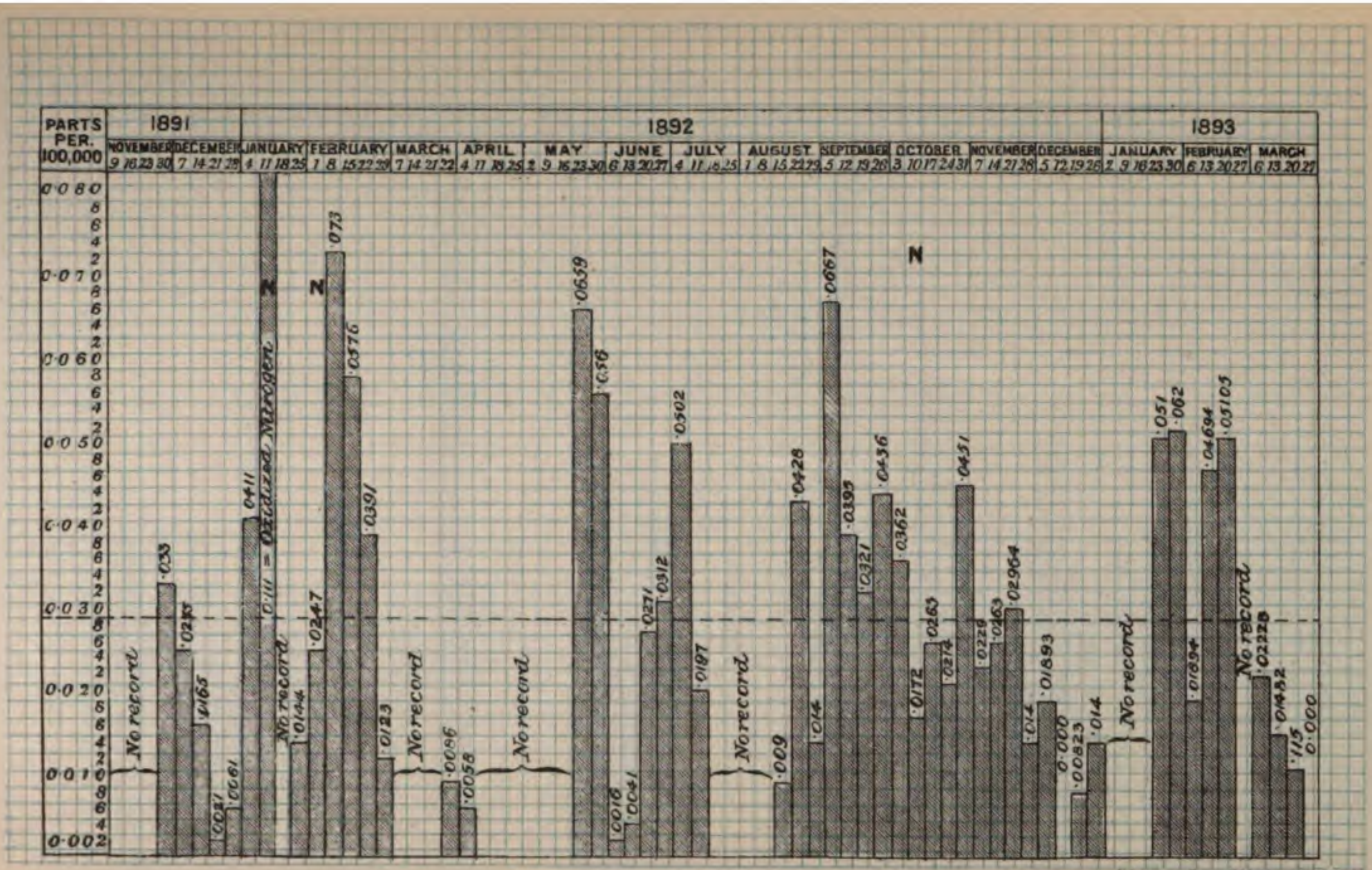
N = *Neutral Reaction.*

Wyman & Sons, Ltd, Lith 7540·12·95.



N = Neutral Reaction.

Wyman & Sons, Ld, Lith 7540-12-95

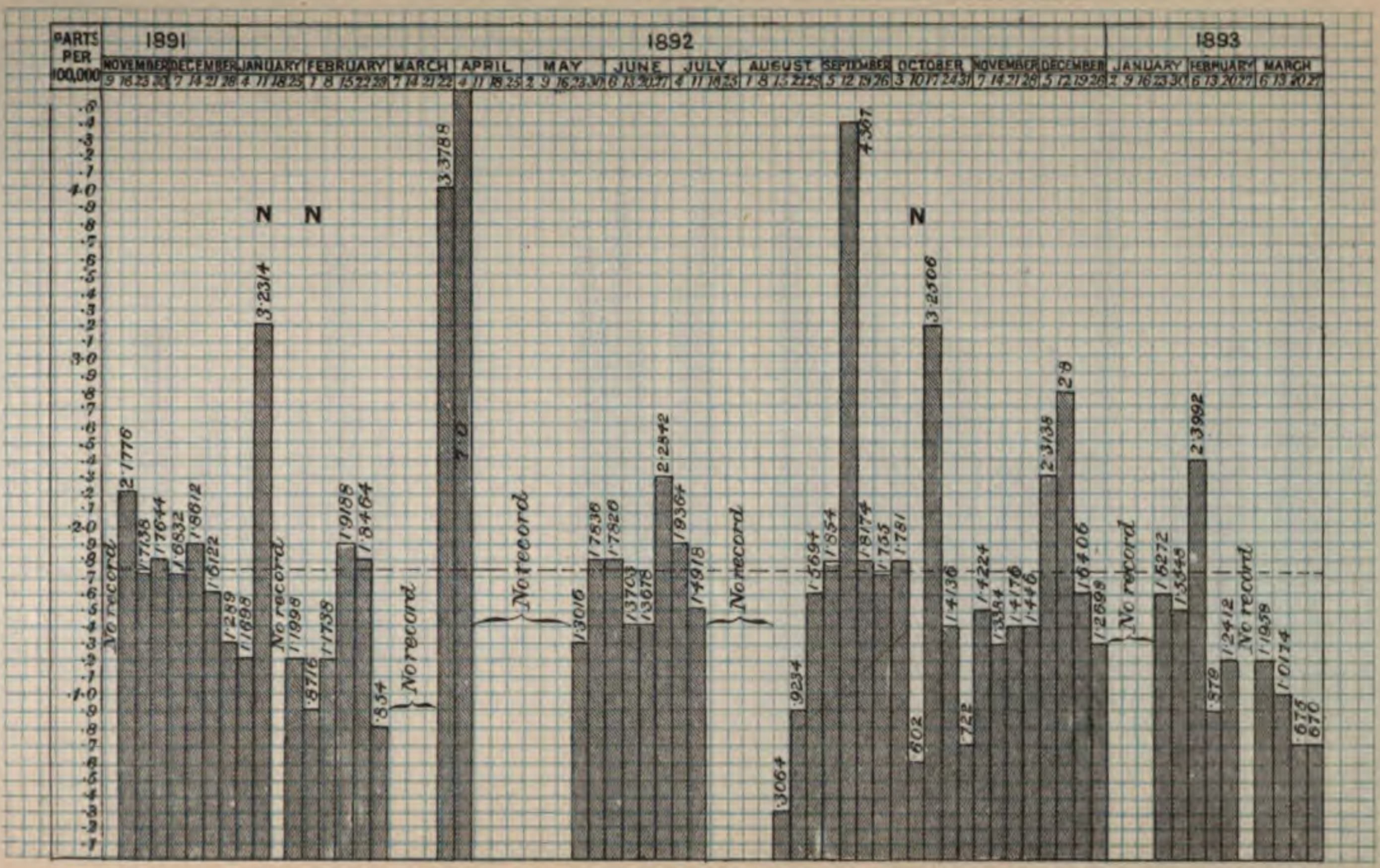


Wyman & Sons, Ltd, Lith. 7640·12·95.

N-Neutral Reaction.

SHOWING NATE OF THE

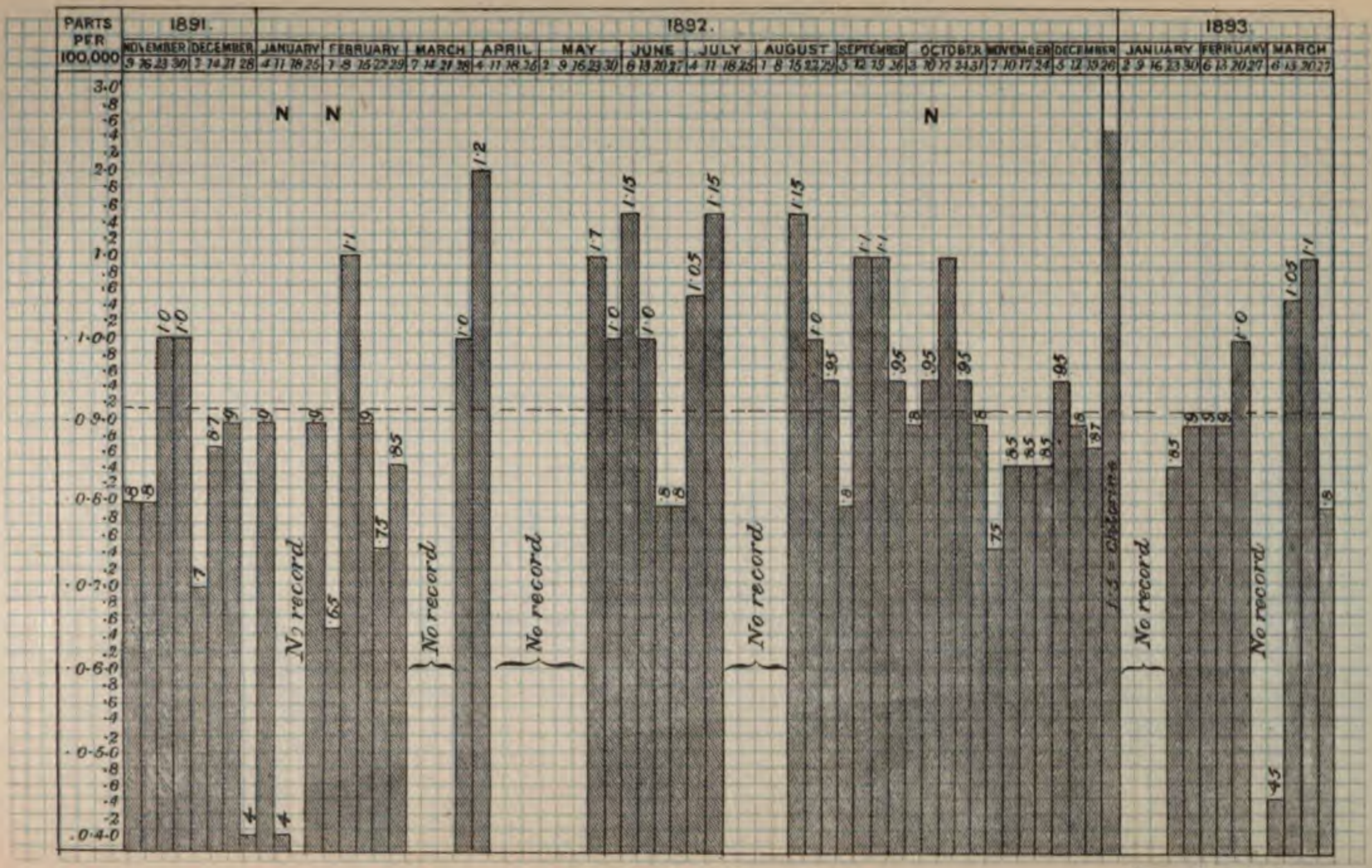
# CHEMICAL EXAMINATION OF THE WATER OF BENTHAM MOSS POOL.



N = *Neutral Reaction.*

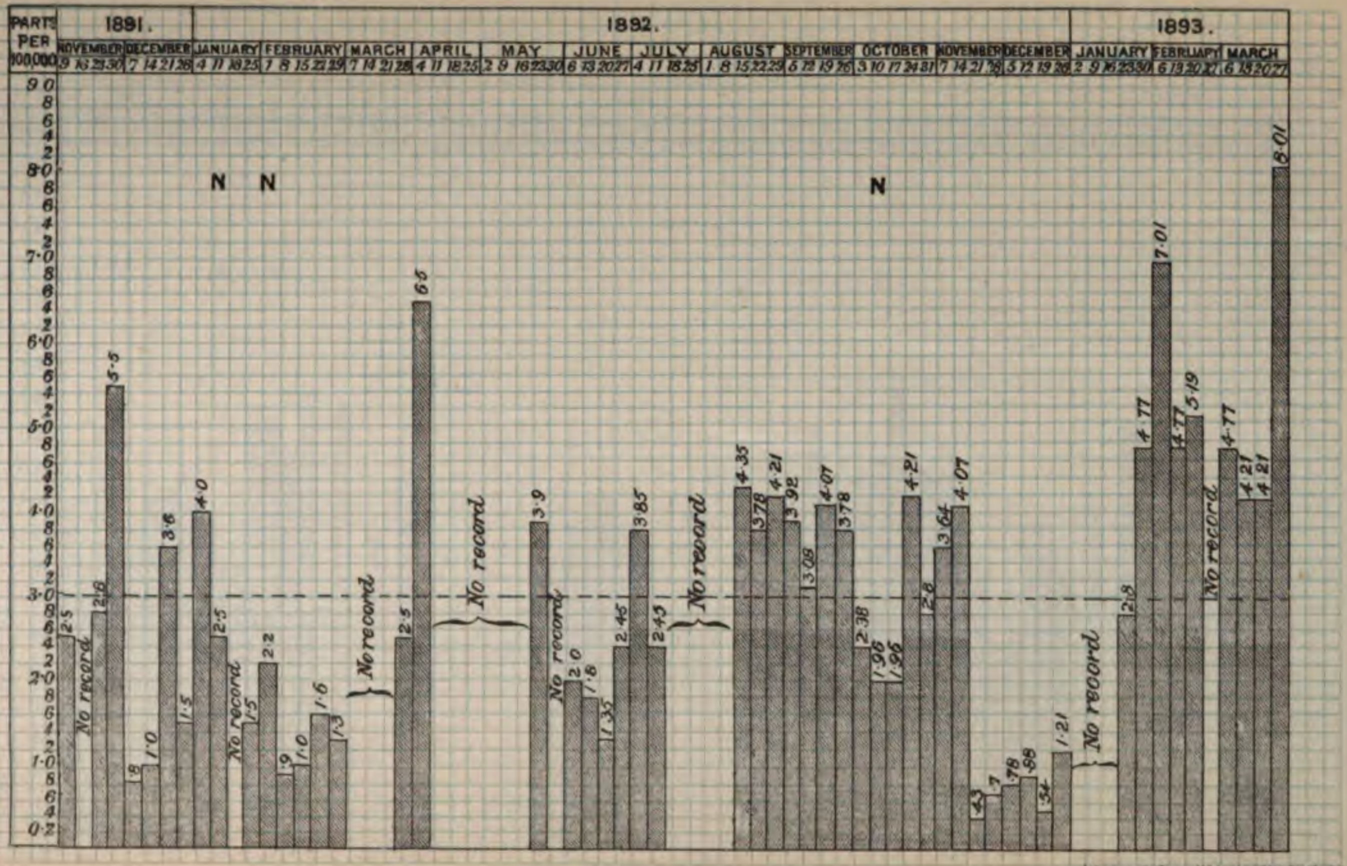
Wyman & Sons, Ld, Lith 7540-12-93.

OF THE WATER OF BENTHAM MOSS POOL.



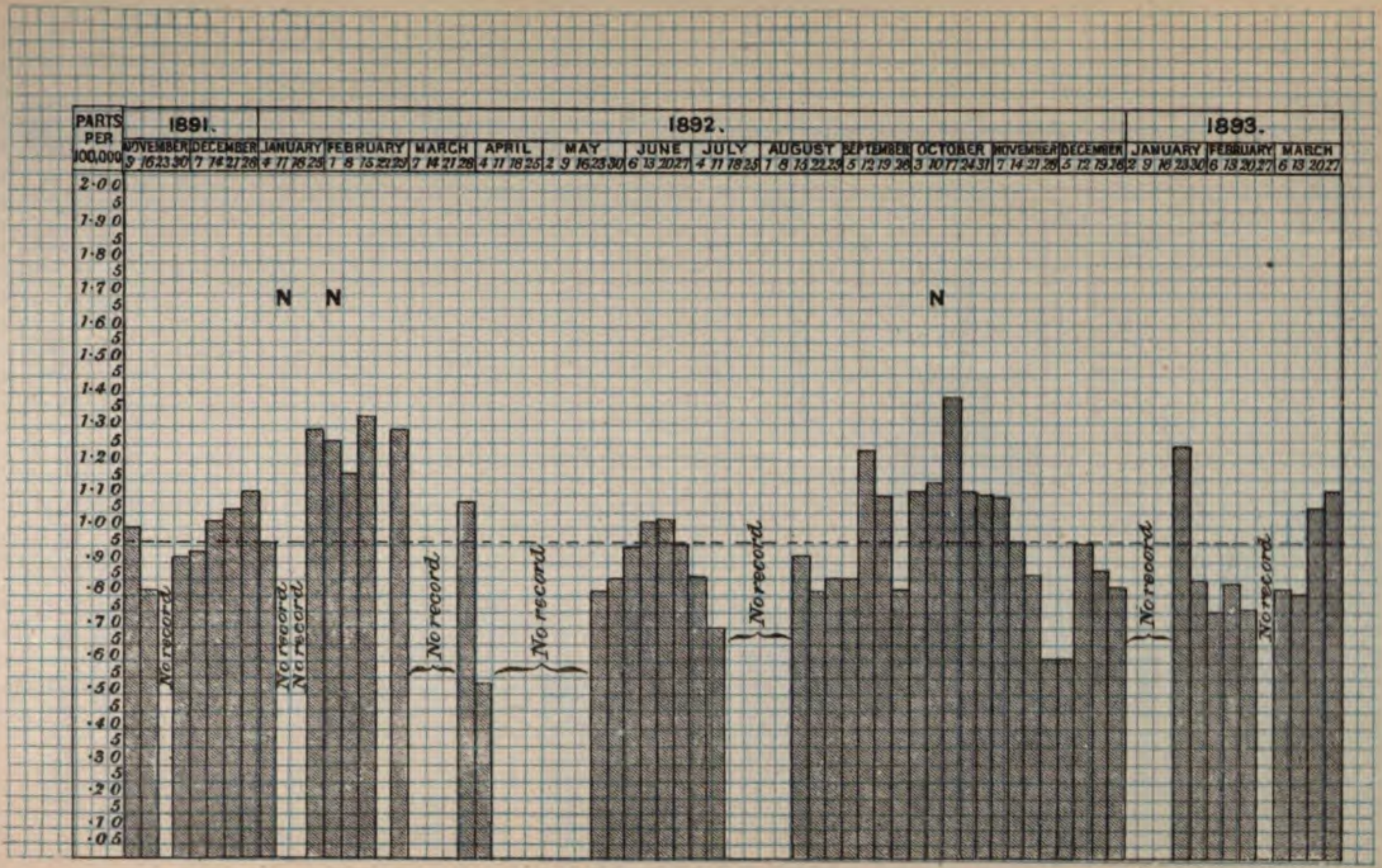
N = *Neutral Reaction.*

Wyman & Sons, Ltd., Lith 7540 · 12 · 95



Wyman & Sons, Ld, Lith. 7340·12·95.

N = *Neutral Reaction.*



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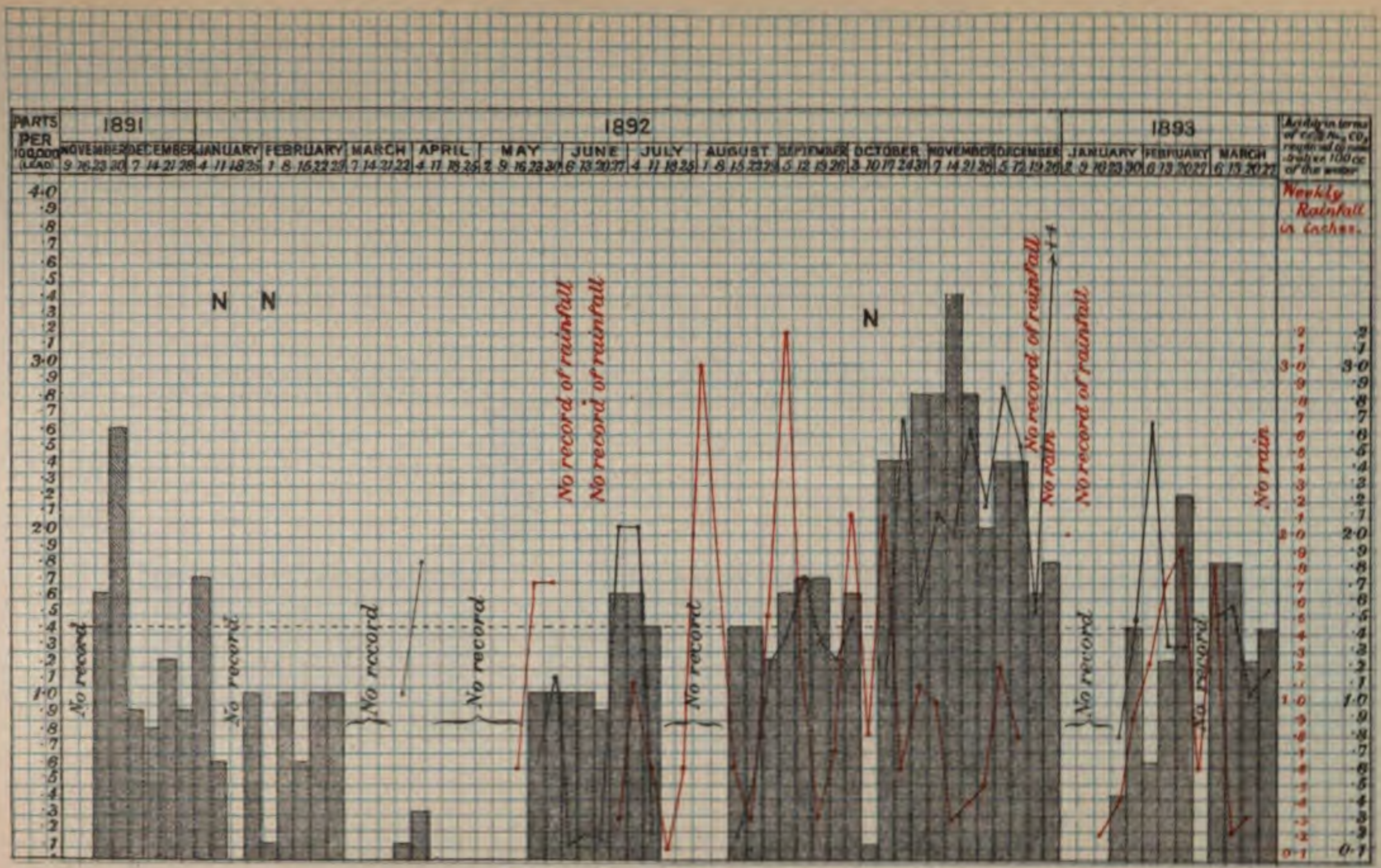
Wyman & Sons, Ld., Lith 7540 · 12 · 95.



**N - Neutral Reaction.**

*The shaded columns refer to the plumbo-solvency, the dotted black line refers to the acidity & the dotted red line to the rainfall.*

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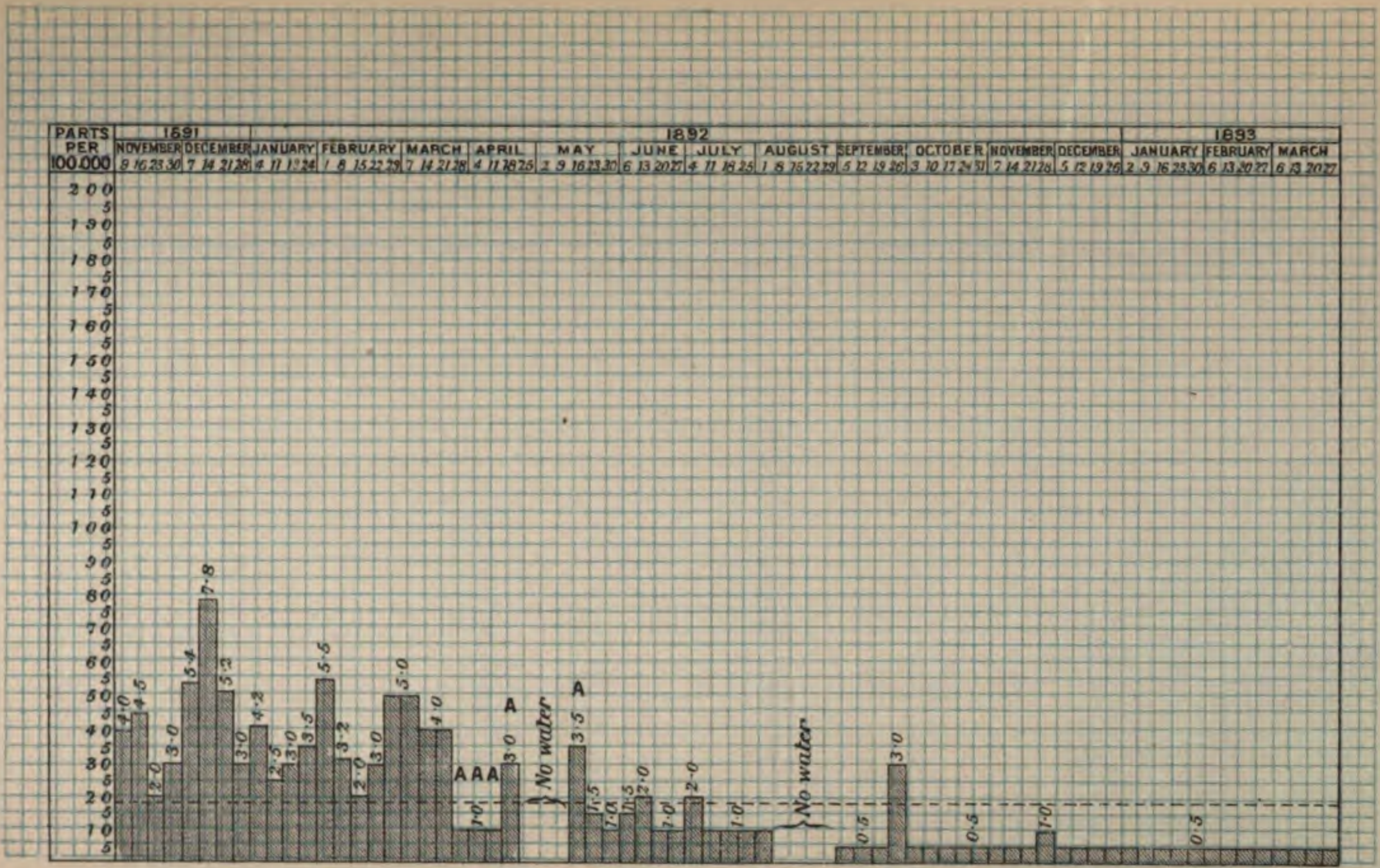
Wyman & Sons, Ld, Lith. 7640·12·95.

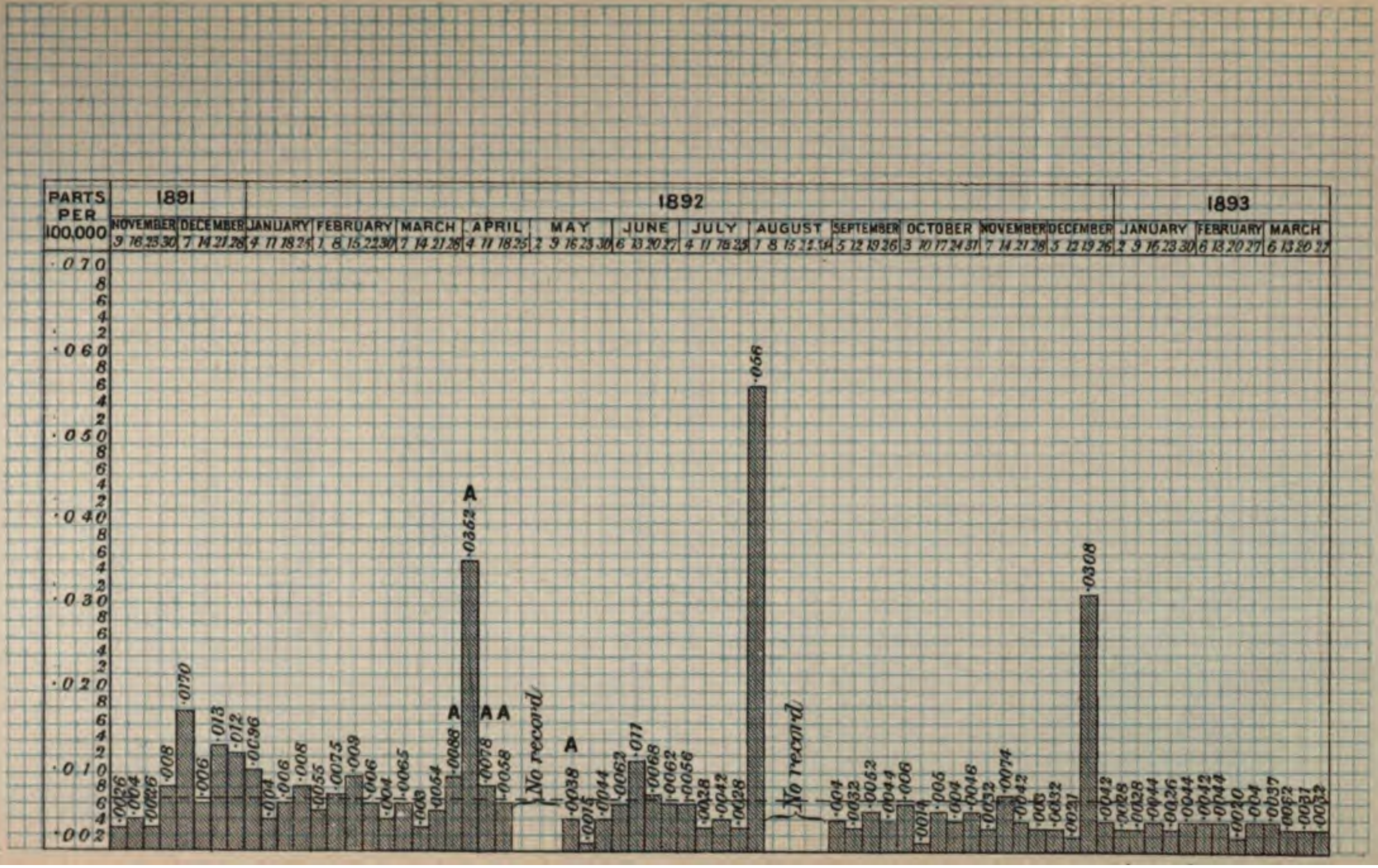


A=Acid Reaction.

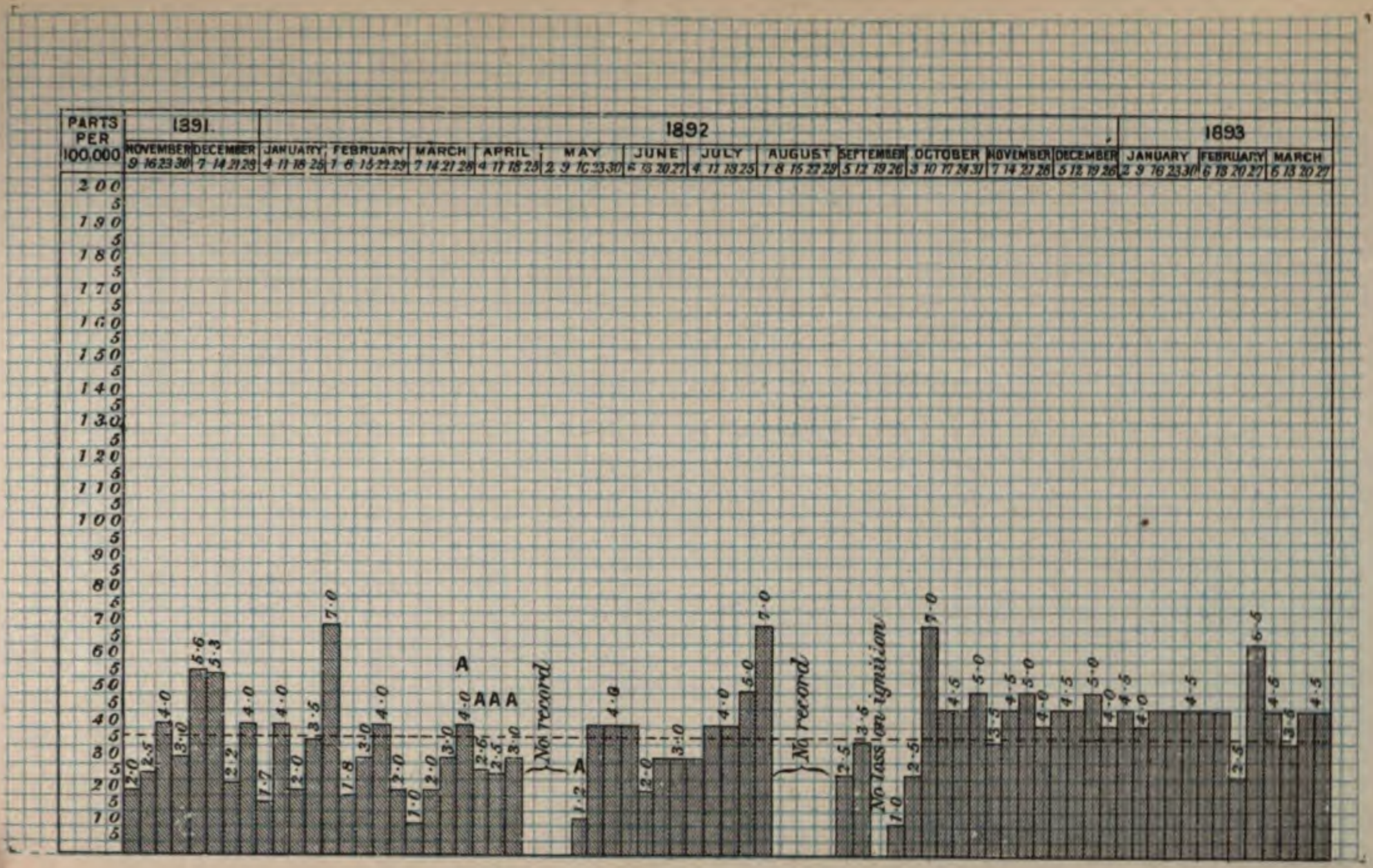
Wyman & Sons, Ltd Lith 7540·12·85.

SHOWING THE RESULTS AS REGARDS FREE AMMONIA OF THE CHEMICAL EXAMINATION

OF THE WATER OF BENTHAM SRRING No 2.

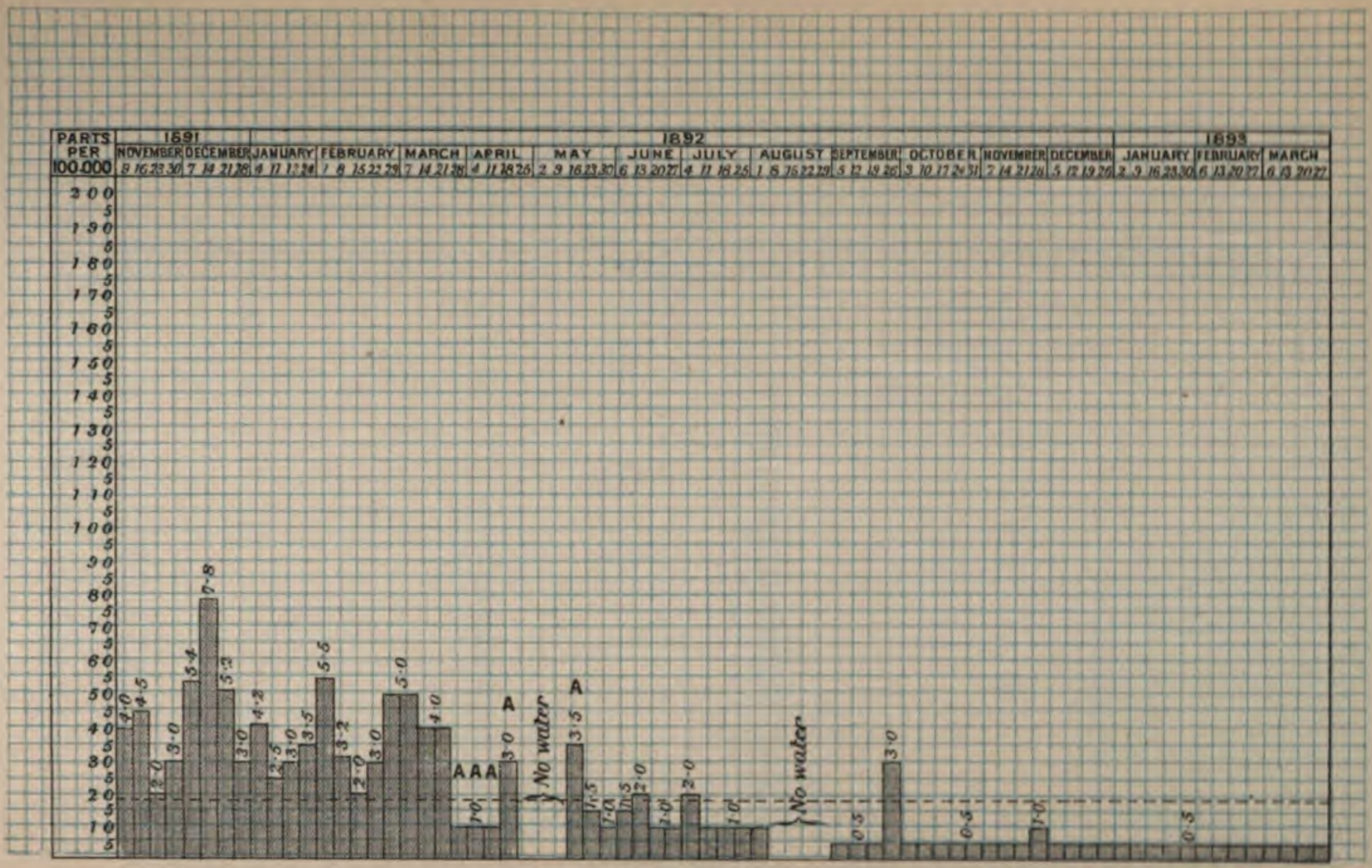


SPRING No. 2.



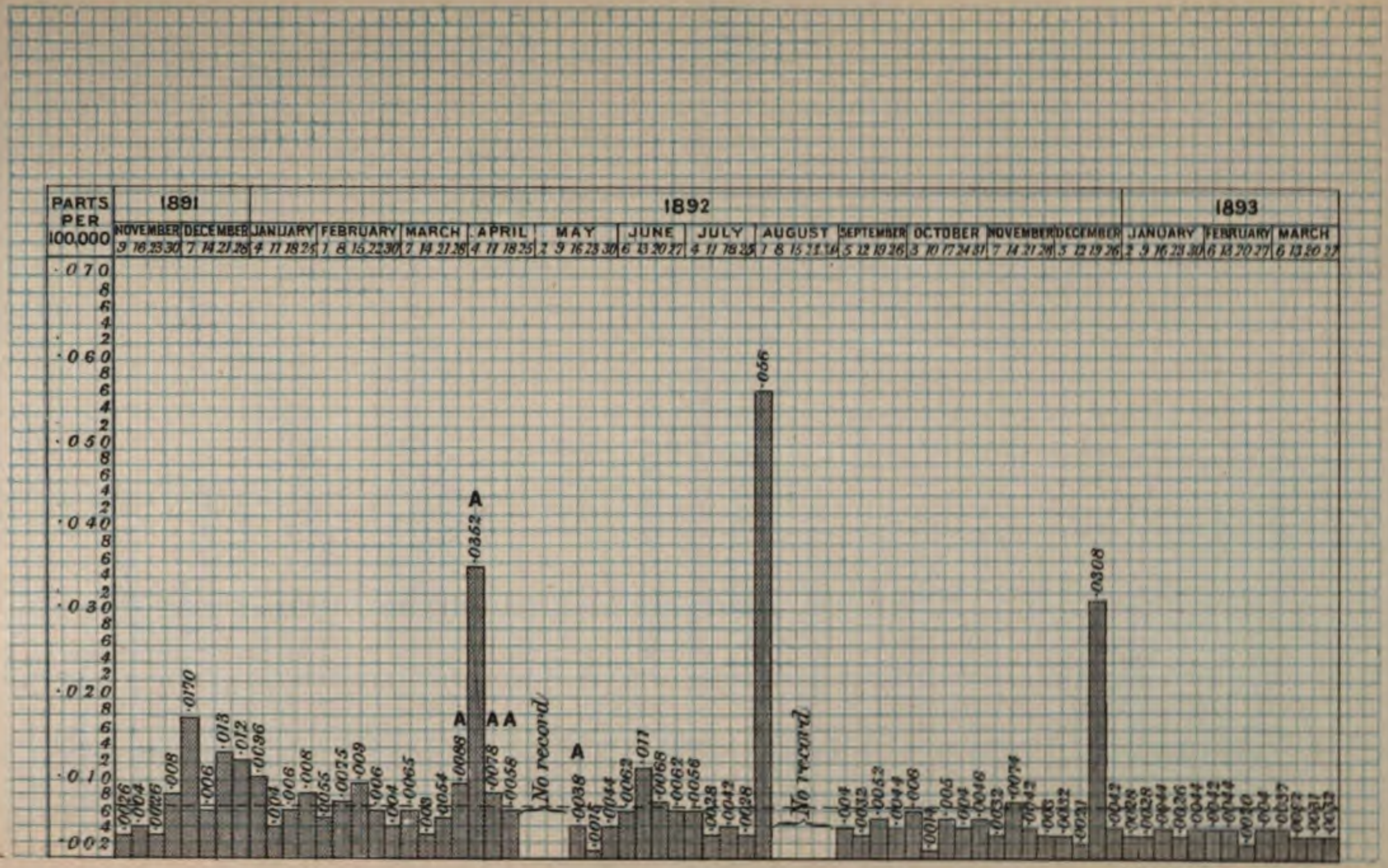
A=*Acid Reaction.*

Wyman & Sons, Ltd., Lith 7540-12-95.



A=*Acid Reaction.*

Wyman & Sons, Ld Lith 7640·12·93



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Wyman & Sons Ltd, Lith 7640·12·93.
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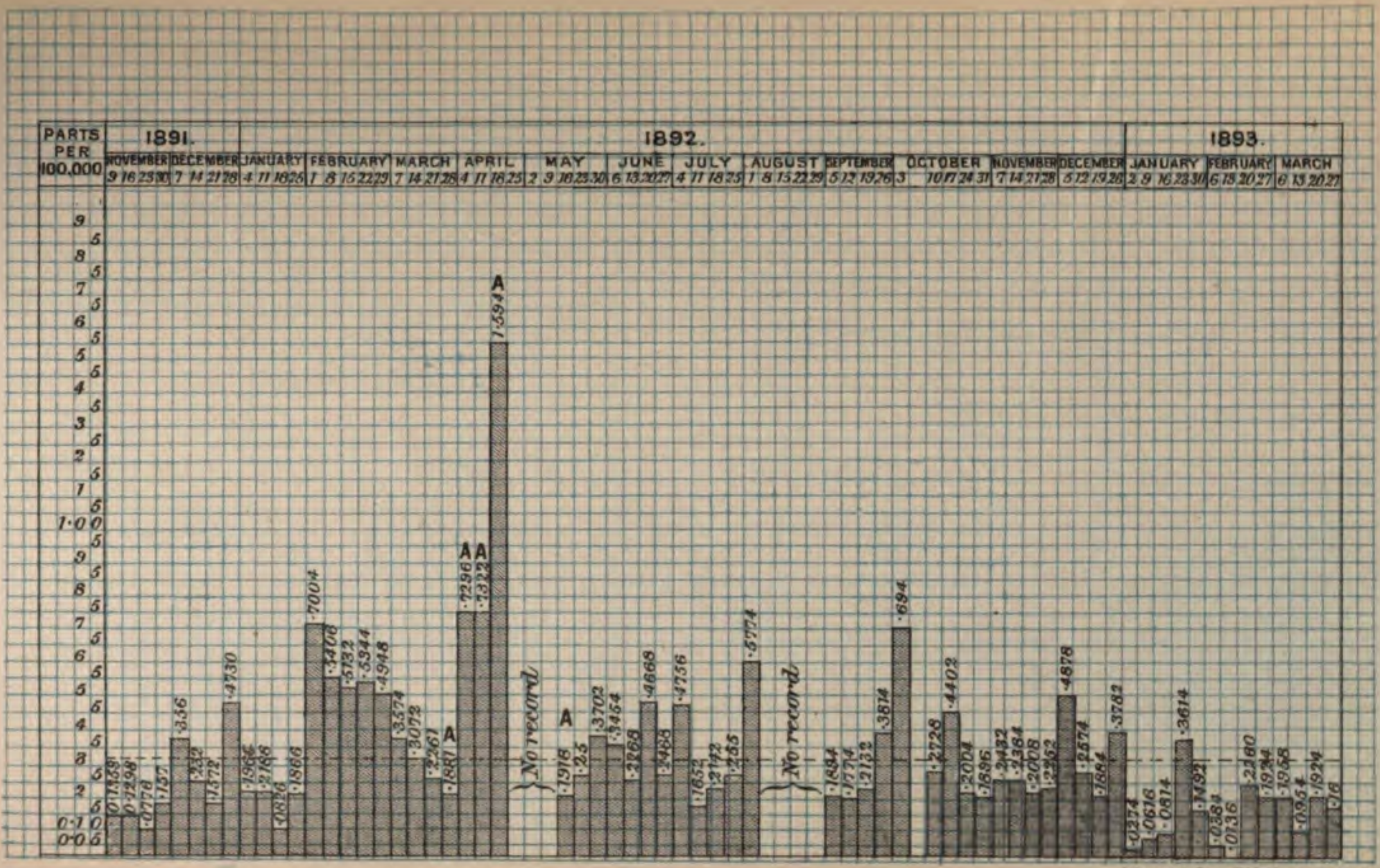
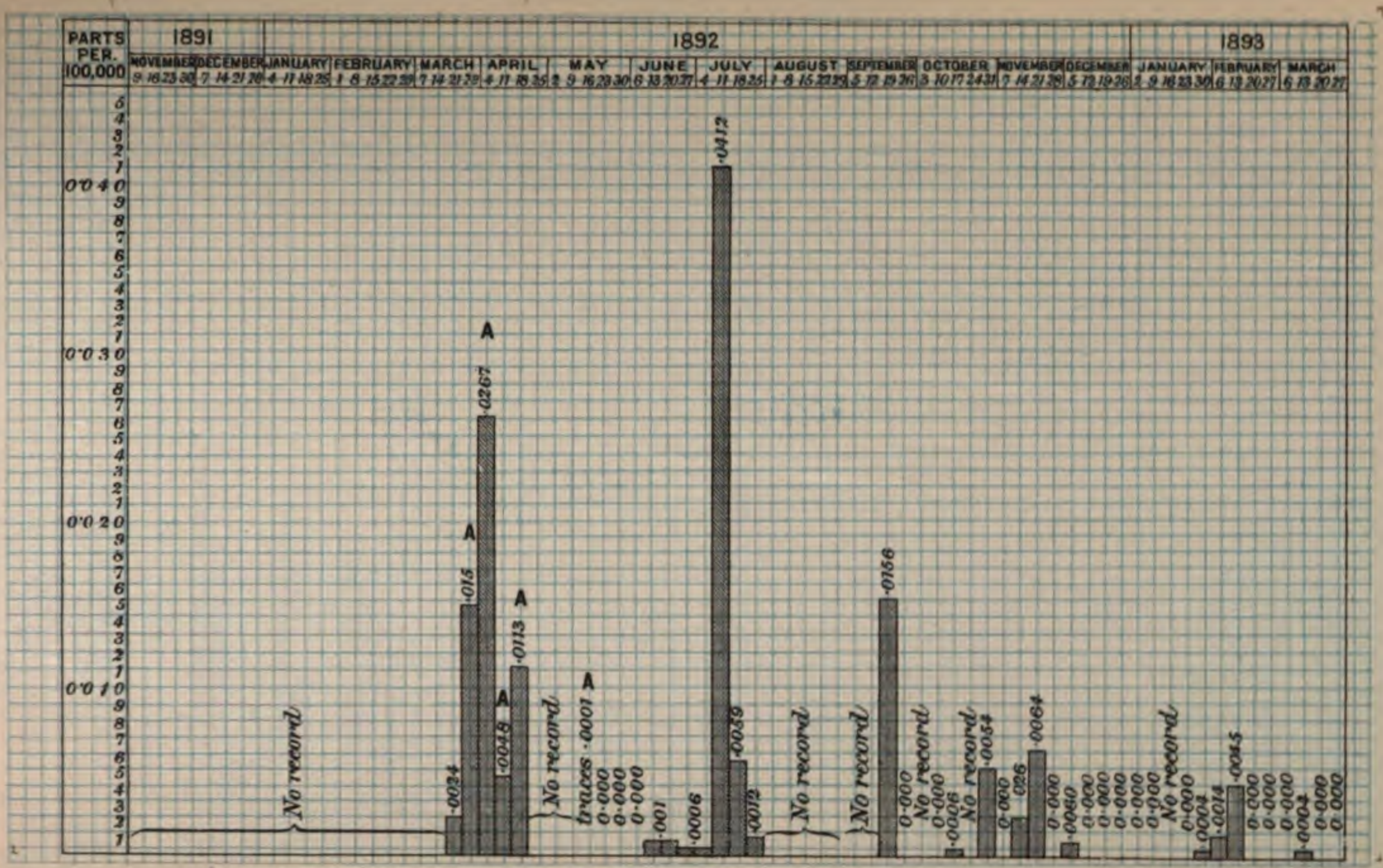


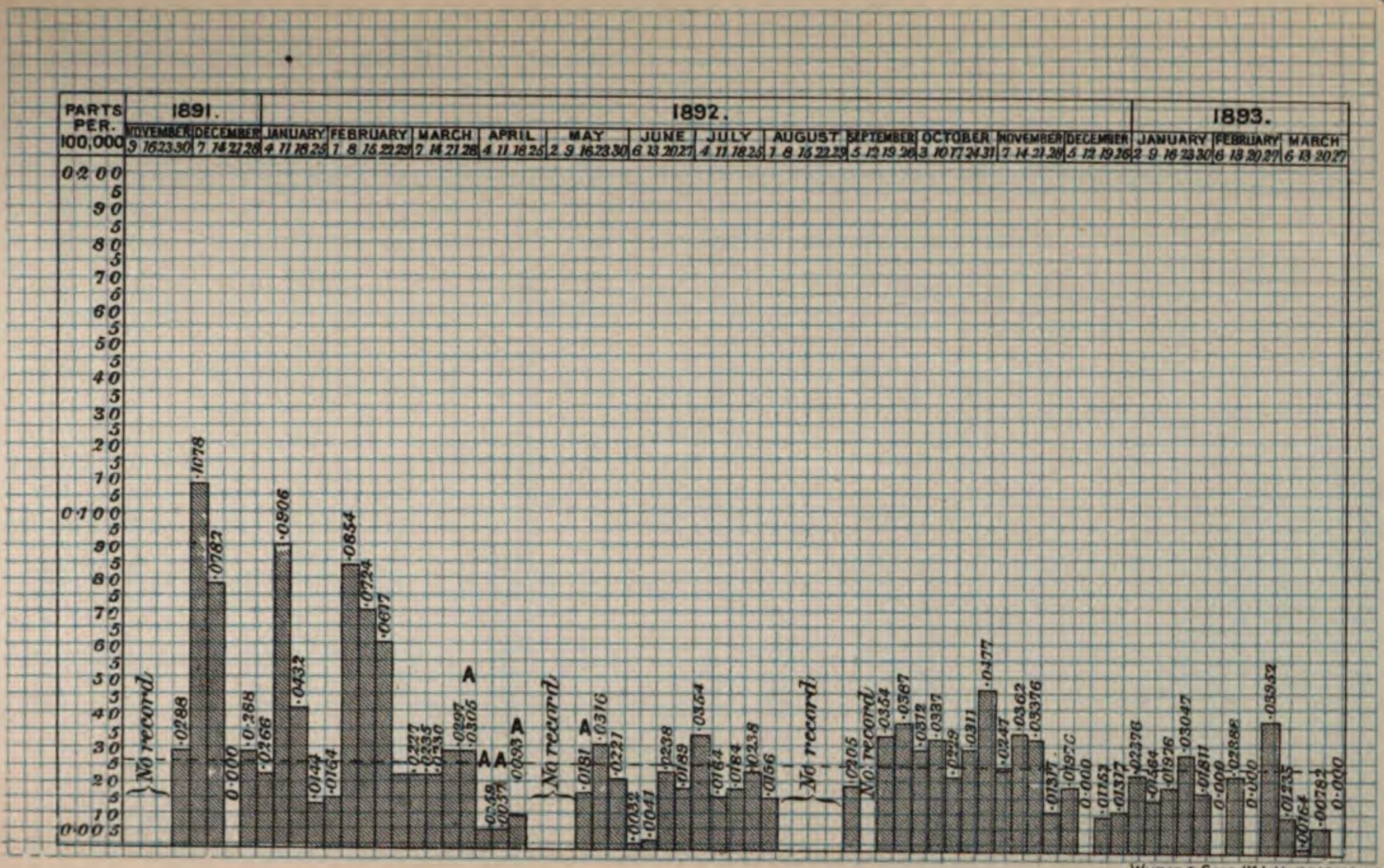
Wyman & Sons, Ld, Lith, 7540-12-95.

A = Acid Reaction.



A=*Acid Reaction.*

Wyman & Sons, Ltd, Lith 7540·11·95



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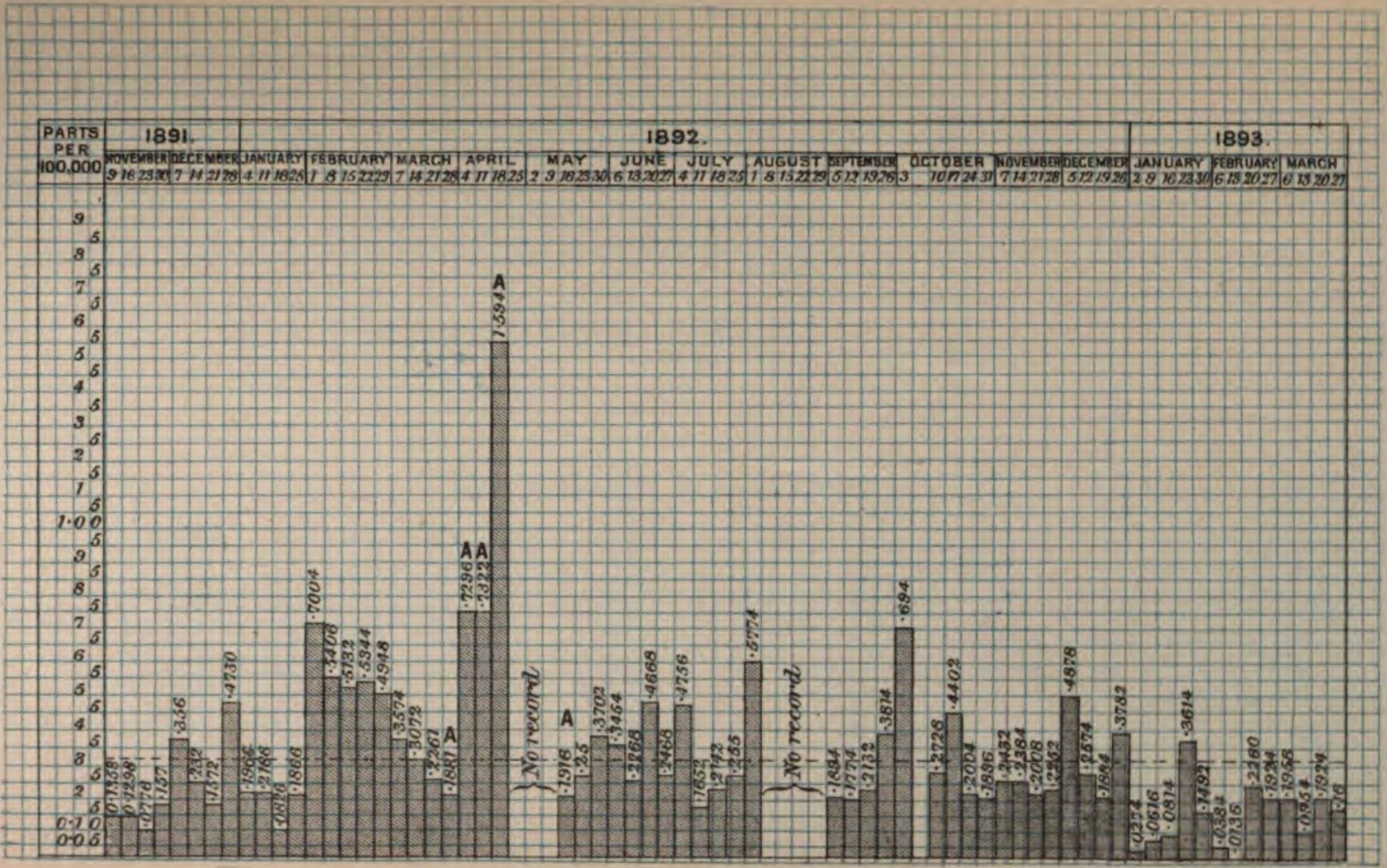
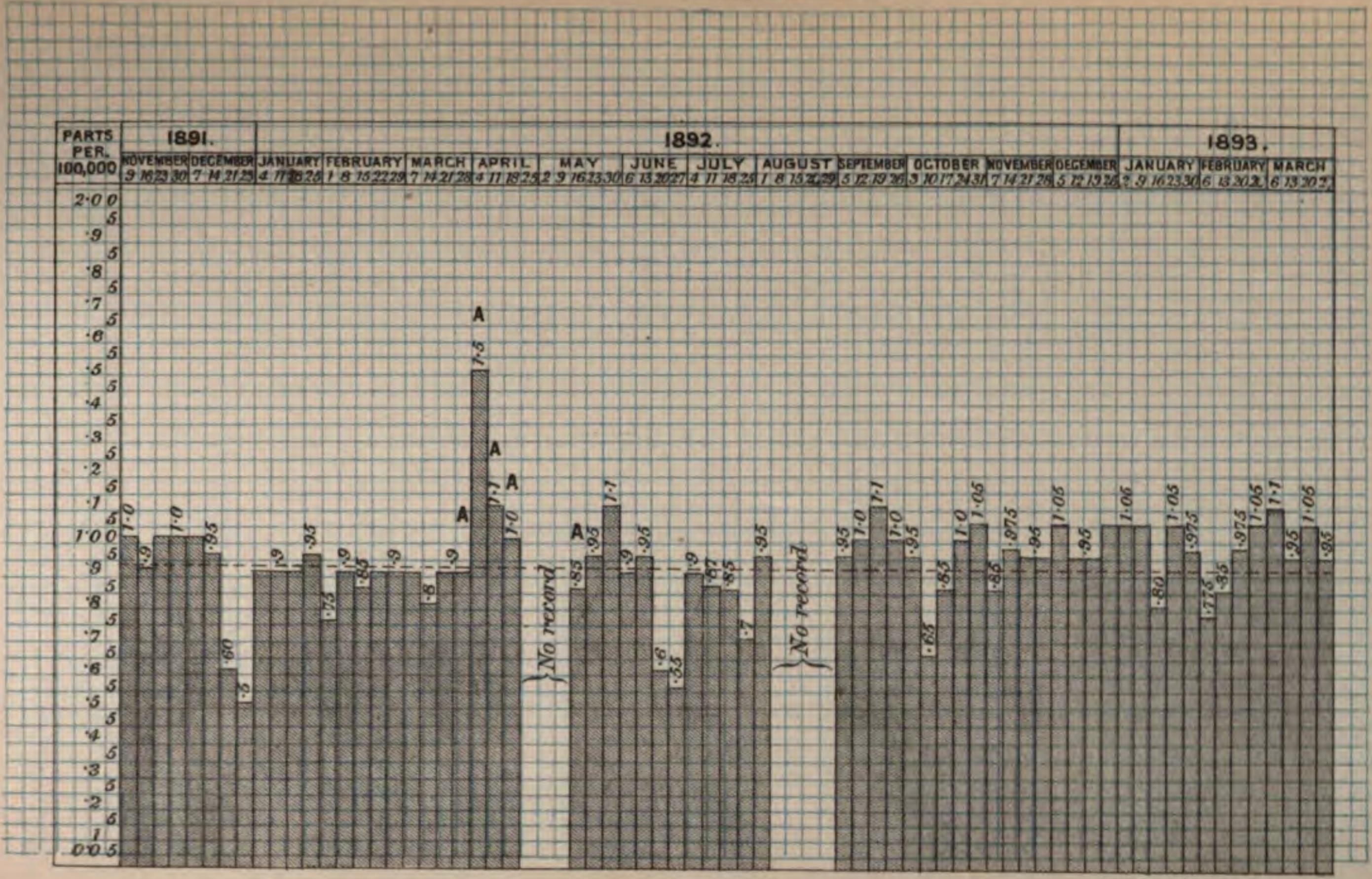


Wyman & Sons, Ld., Lith. 7040·12·93.

A = *Acid Reaction.*

SHOWING THE RESULTS AS REGARDS CHLORINE, OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM SPRING Nº 2.



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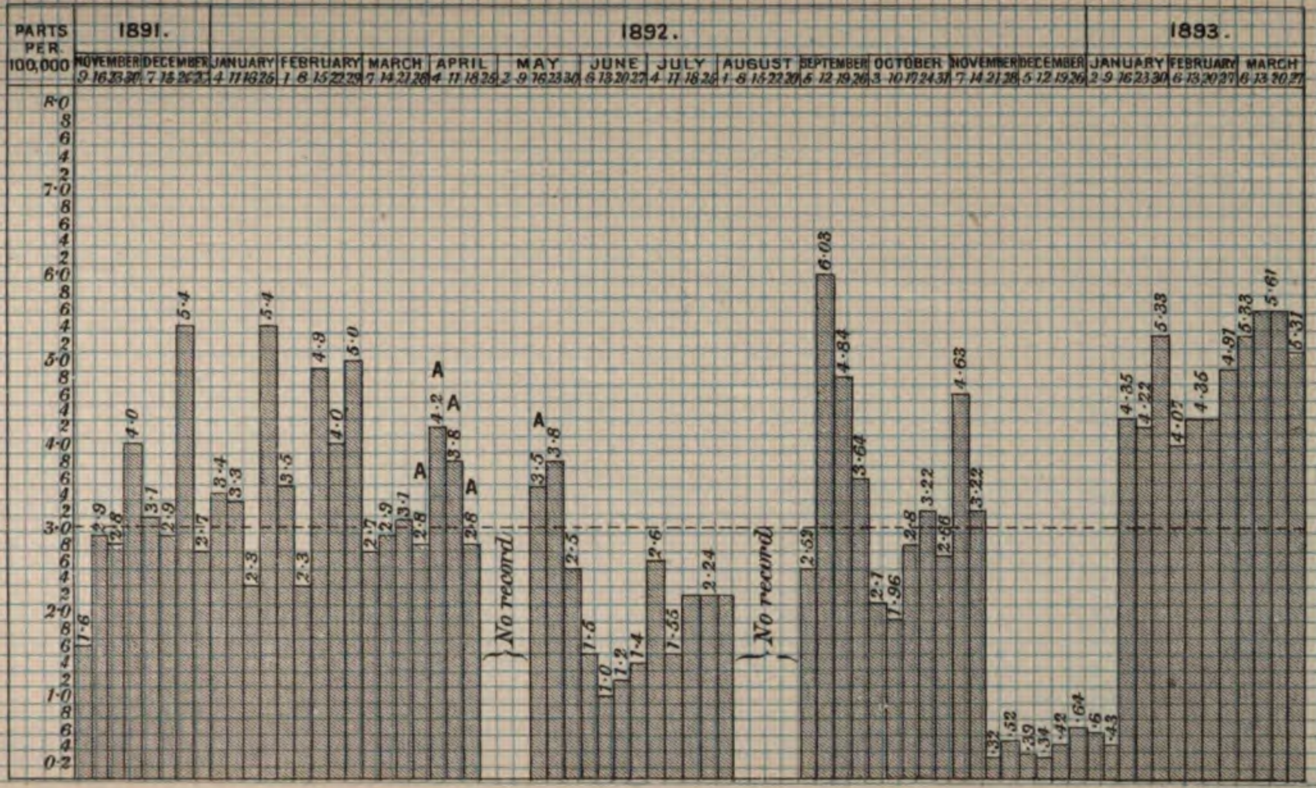
Wyman & Sons, Lᵈ, Lith. 7540 · 12 · 95.



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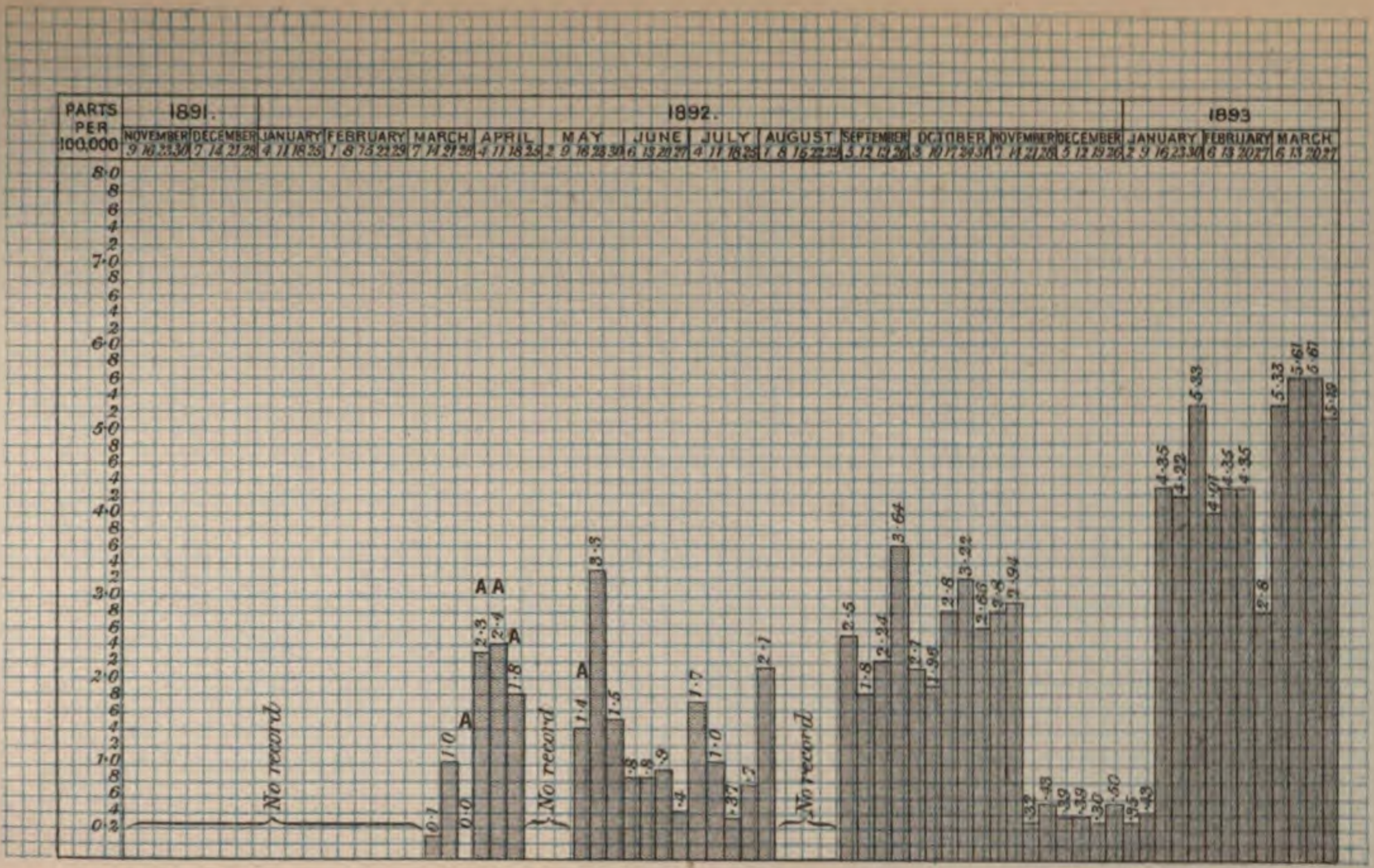
A = *Acid Reaction.*

OF THE WATER OF BENTHAM SPRING No. 2.



A=*Acid Reaction.*

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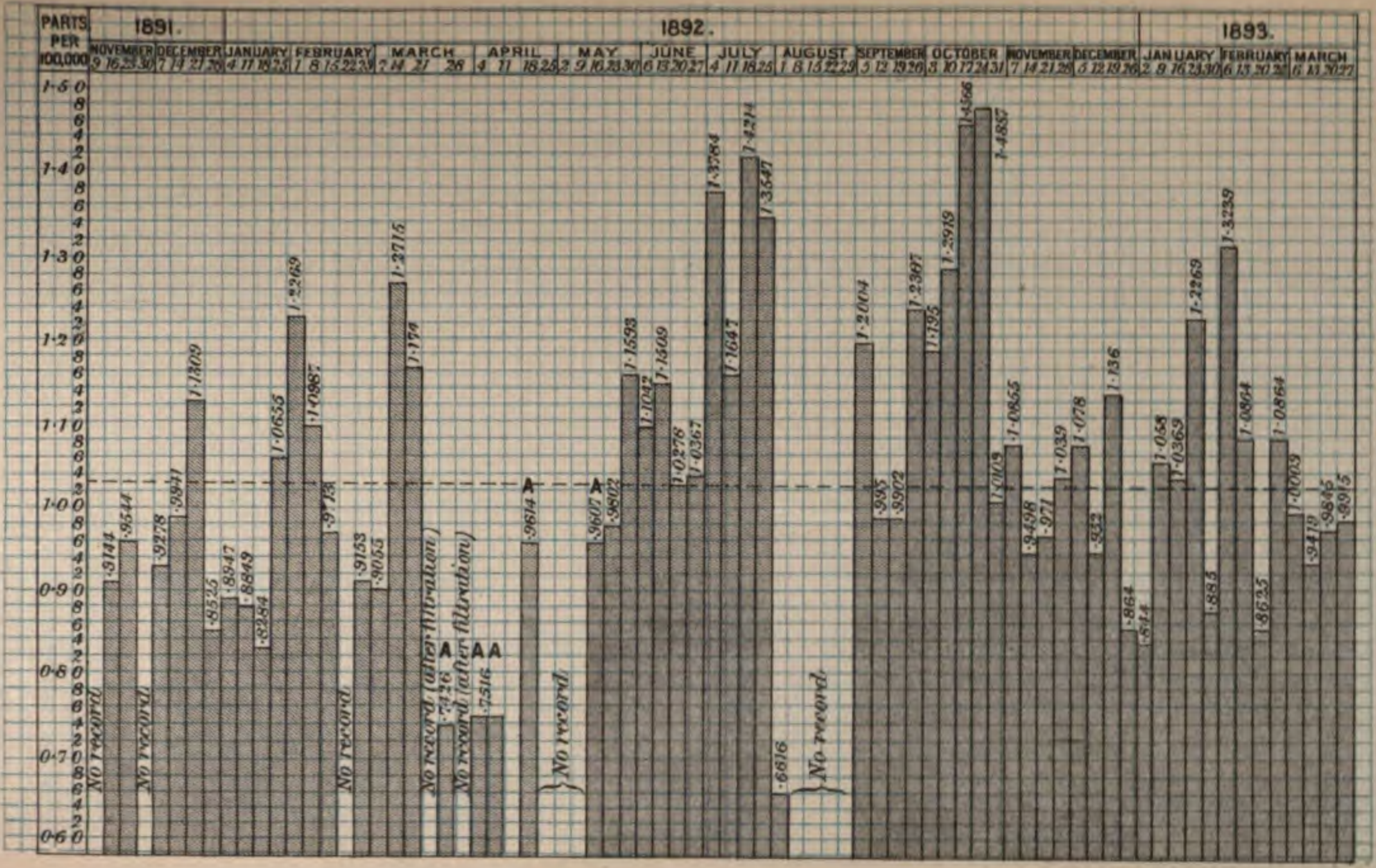
# OF THE WATER OF BENTHAM SPRING No. 2.



A = Acid Reaction.

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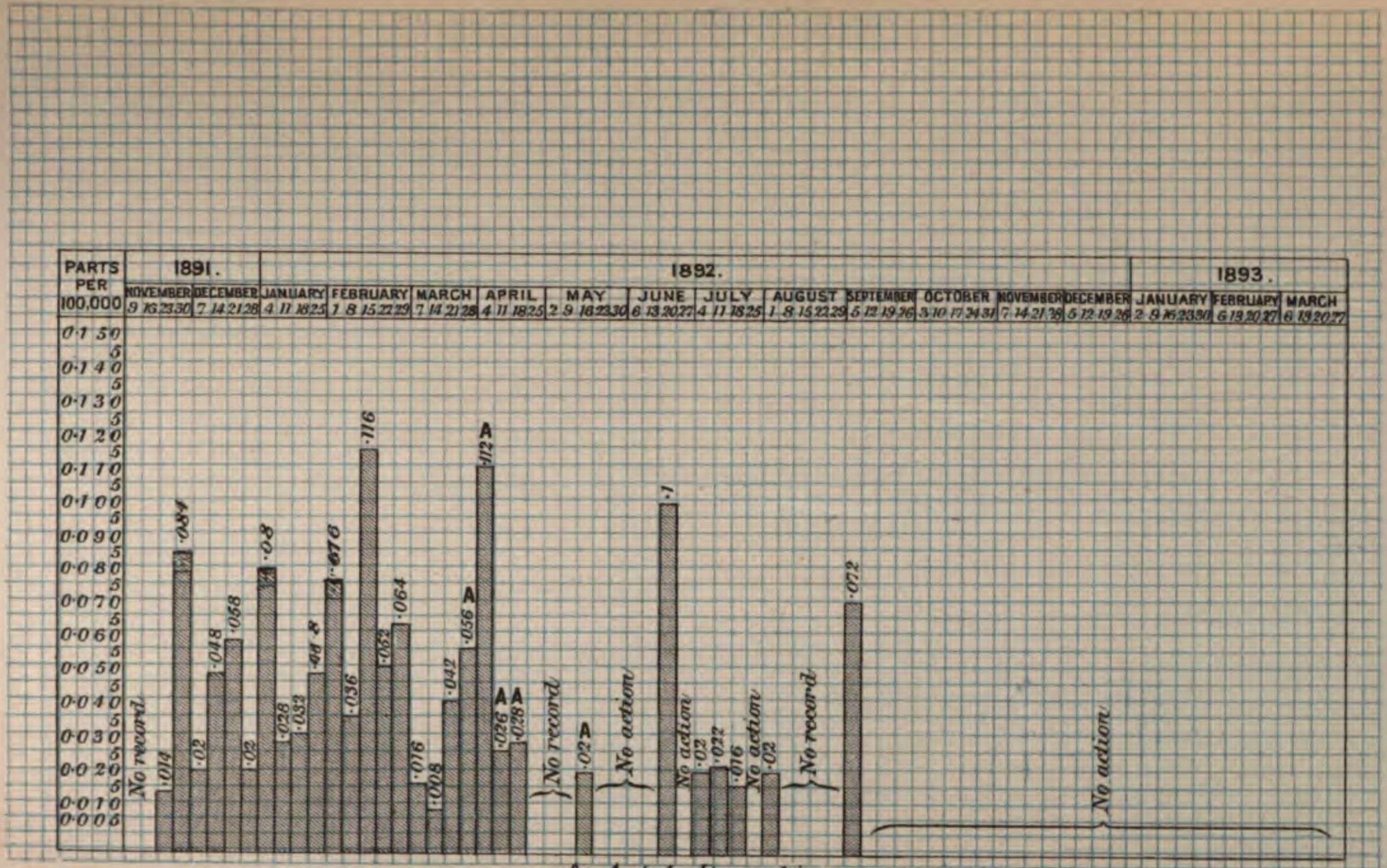
SHOWING THE RESULTS AS REGARDS PLUMBO-SOLVENCY OF THE CHEMICAL EXAMINATION
OF THE WATER OF BENTHAM SPRING Nº2.



A = Acid Reaction.

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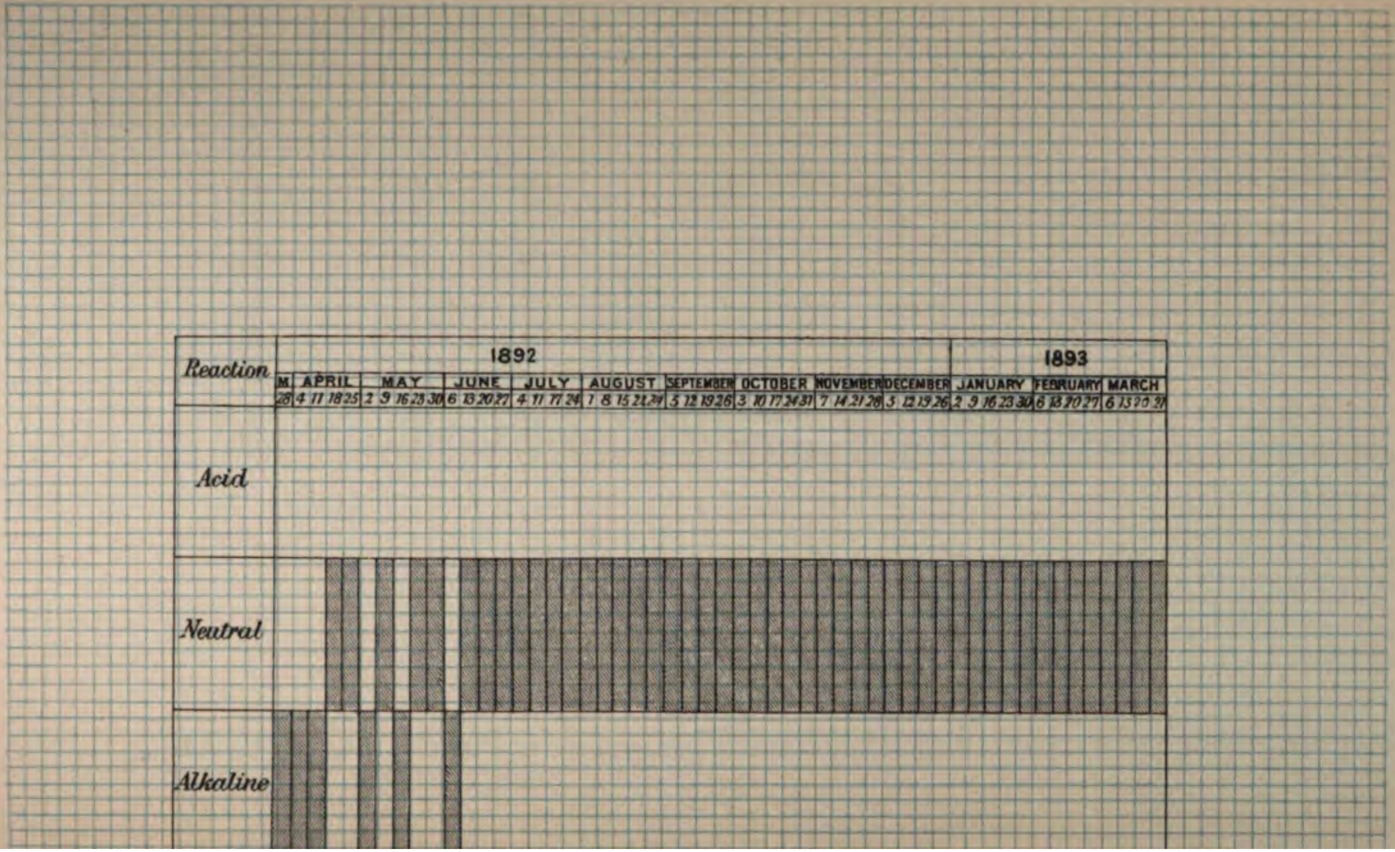
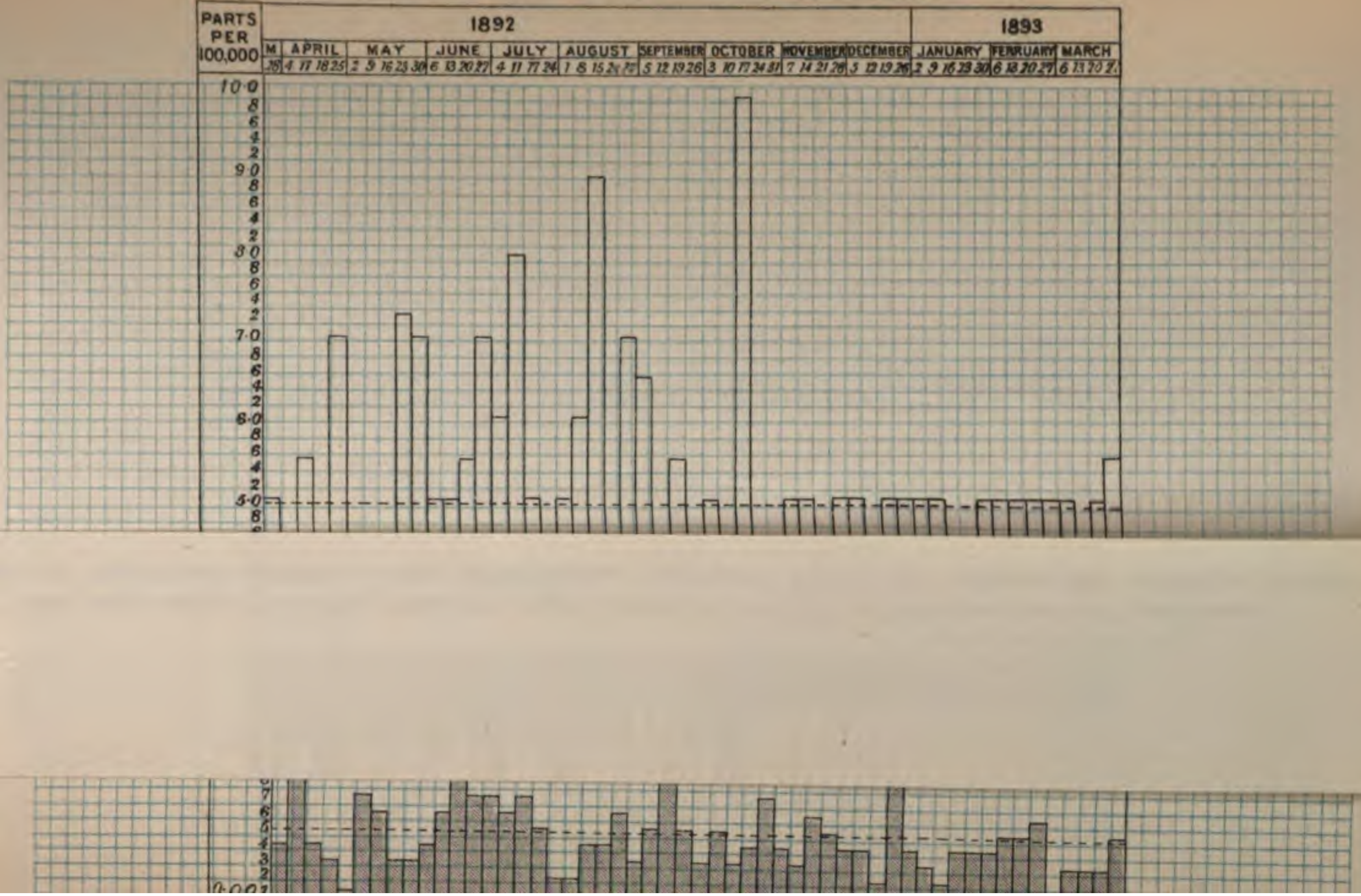
h in the majority of cases the water is represented as having plumbo-solvent ability it must be undestood that nearly

## DIAGRAM 38.

SHOWING THE RESULTS AS REGARDS REACTION OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM BRIGHT SYKE STREAM

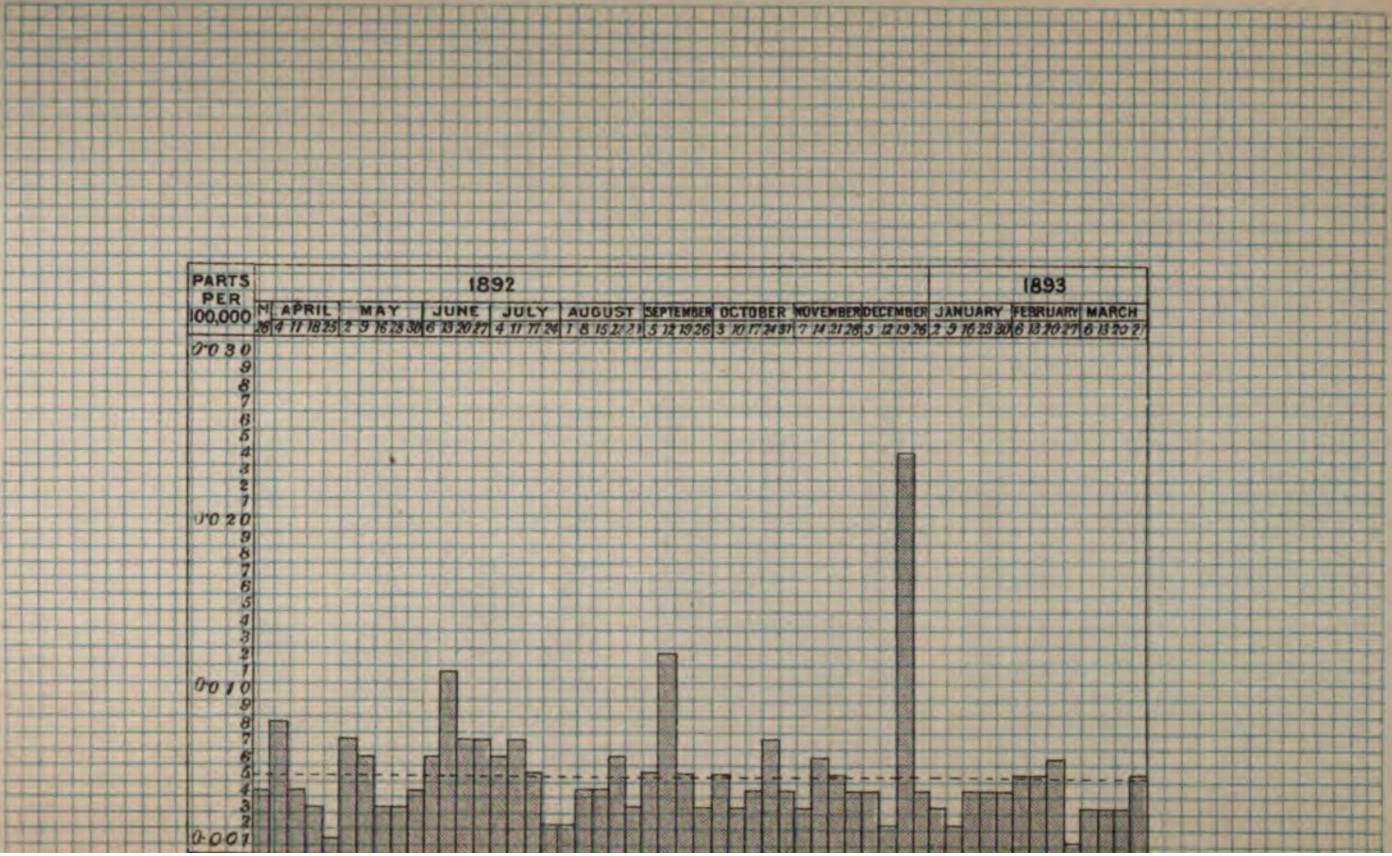


SHOWING THE RESULTS AS REGARDS TOTAL FIXED & VOLATILE SOLIDS OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM BRIGHT SYKE STREAM

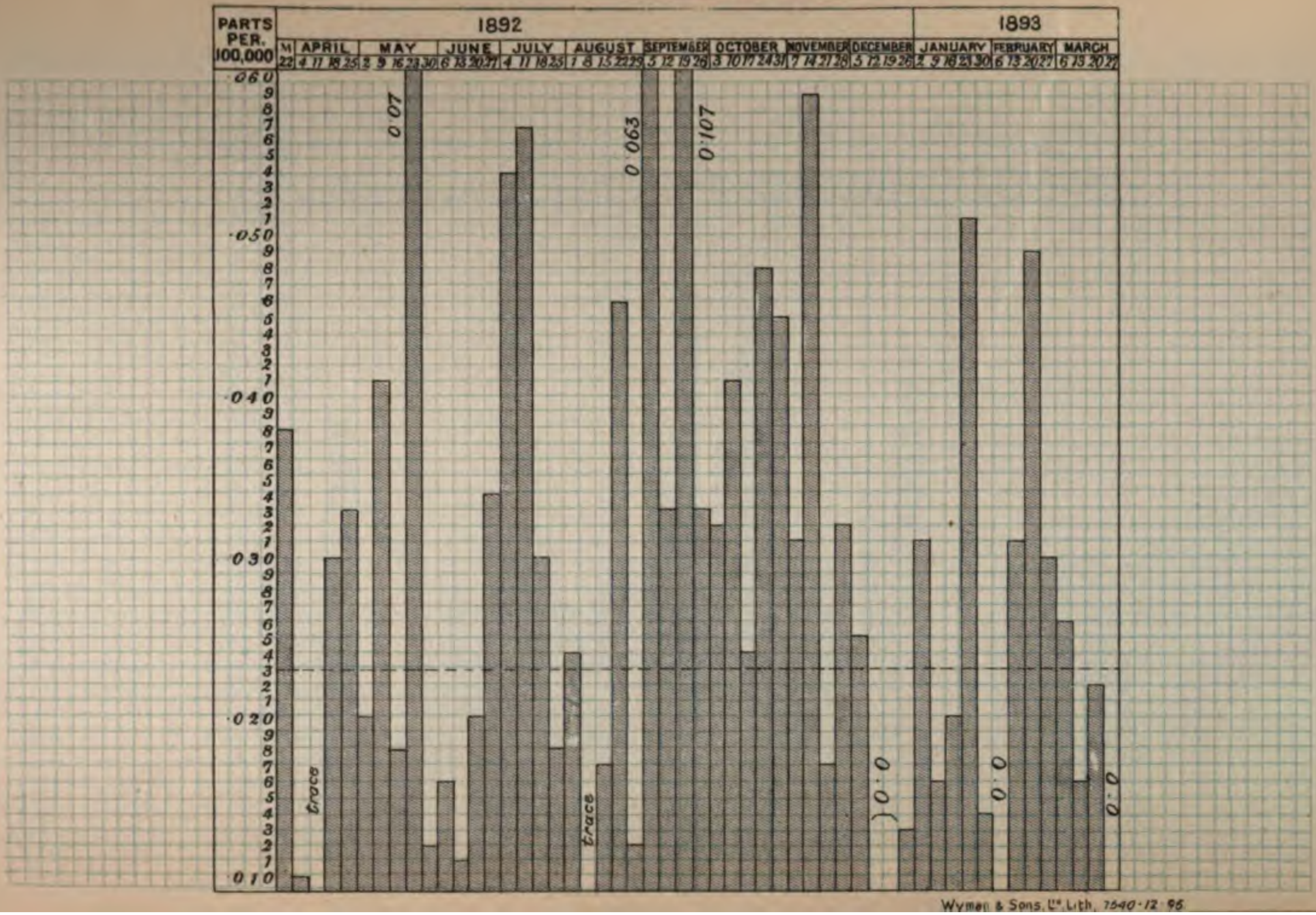


# DIAGRAM 40.

SHOWING THE RESULTS AS REGARDS FREE AMMONIA OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM BRIGHT SYKE STREAM



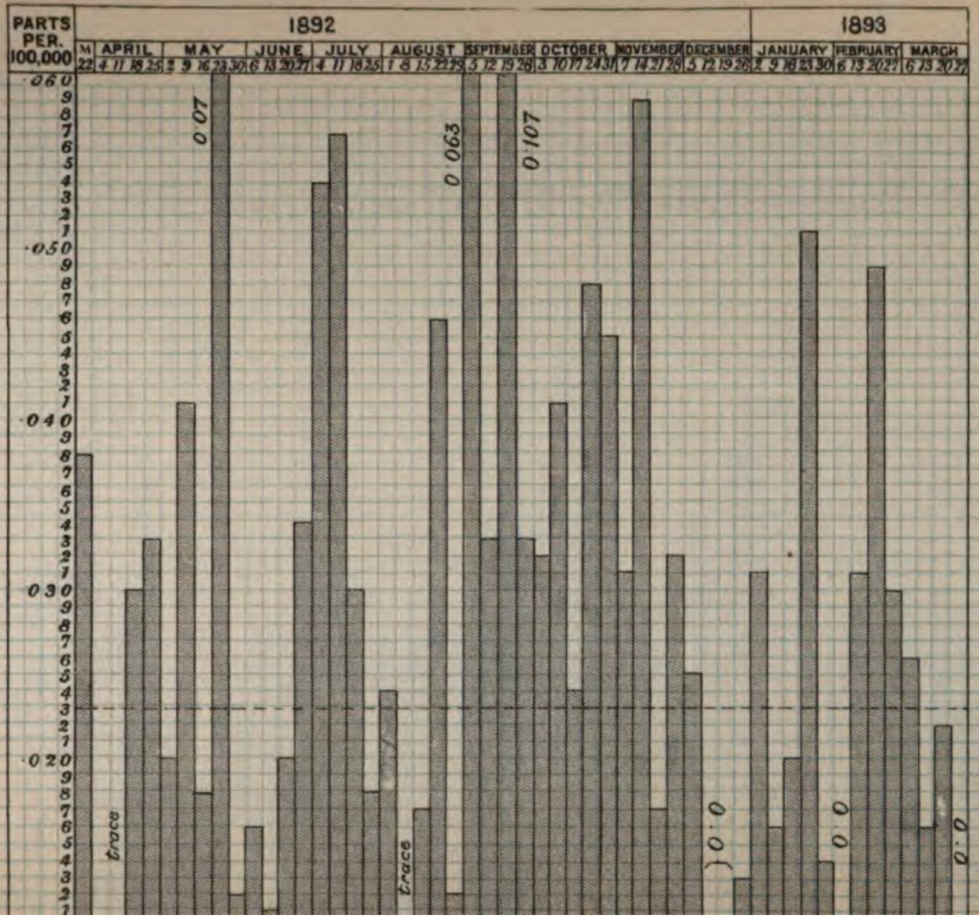
## OF THE WATER OF BENTHAM BRIGHT SYKE STREAM.



Wyman & Sons, Ltd. Lith. 7540·12·95

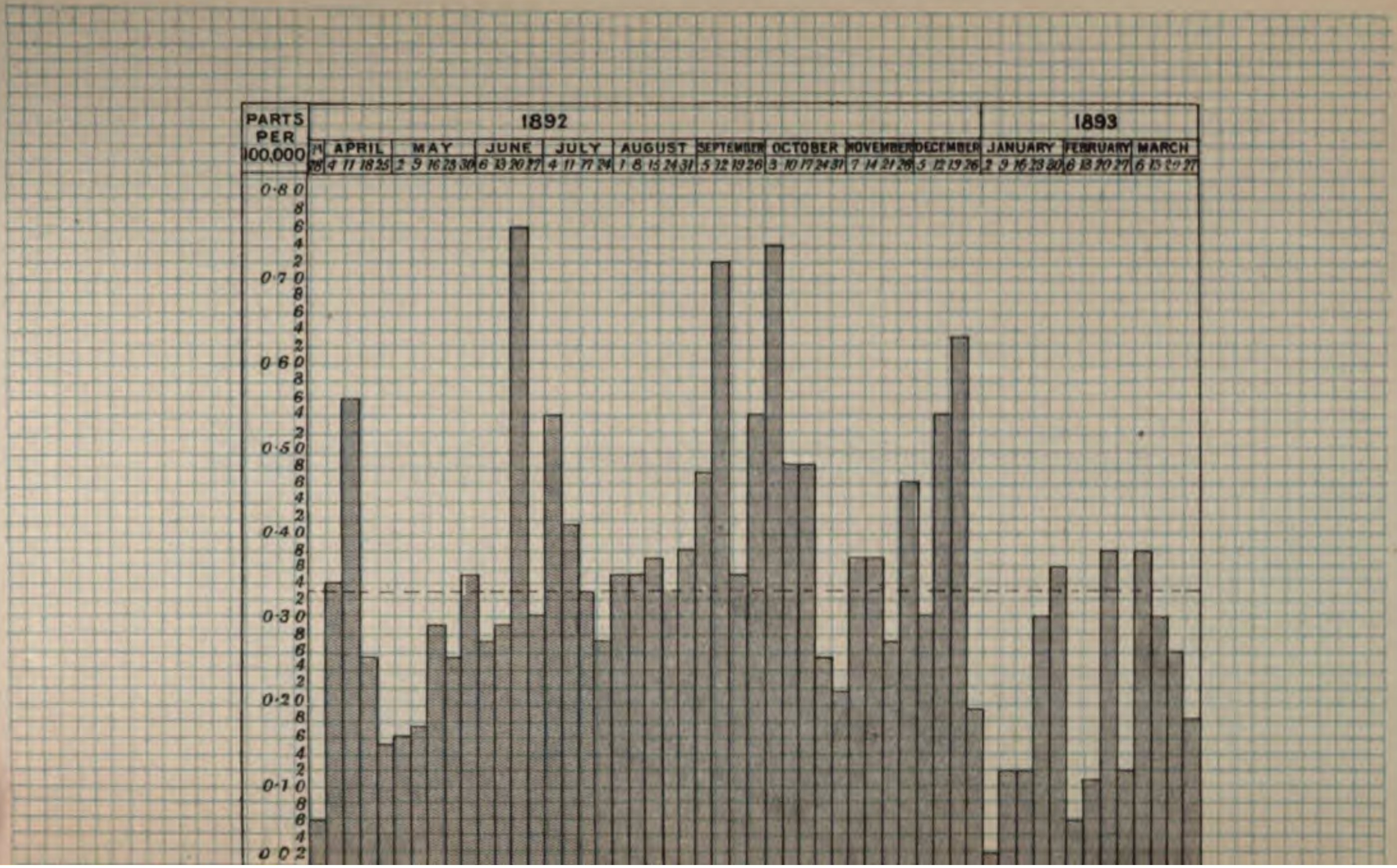
# DIAGRAM 42.

SHOWING THE RESULTS AS REGARDS OXIDISED NITROGEN OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM BRIGHT SYKE STREAM.

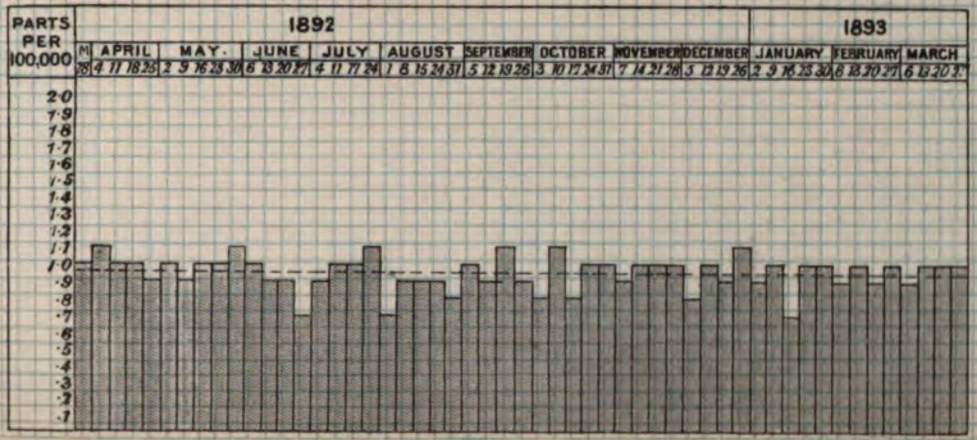


## DIAGRAM 43.

SHOWING THE RESULTS AS REGARDS OXYGEN ABSORBED FROM PERMANGANATE OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM BRIGHT SYKE STREAM.



SHOWING THE RESULTS AS REGARDS CHLORINE OF THE CHEMICAL EXAMINATION OF THE WATER OF BENTHAM BRIGHT SYKE STREAM.



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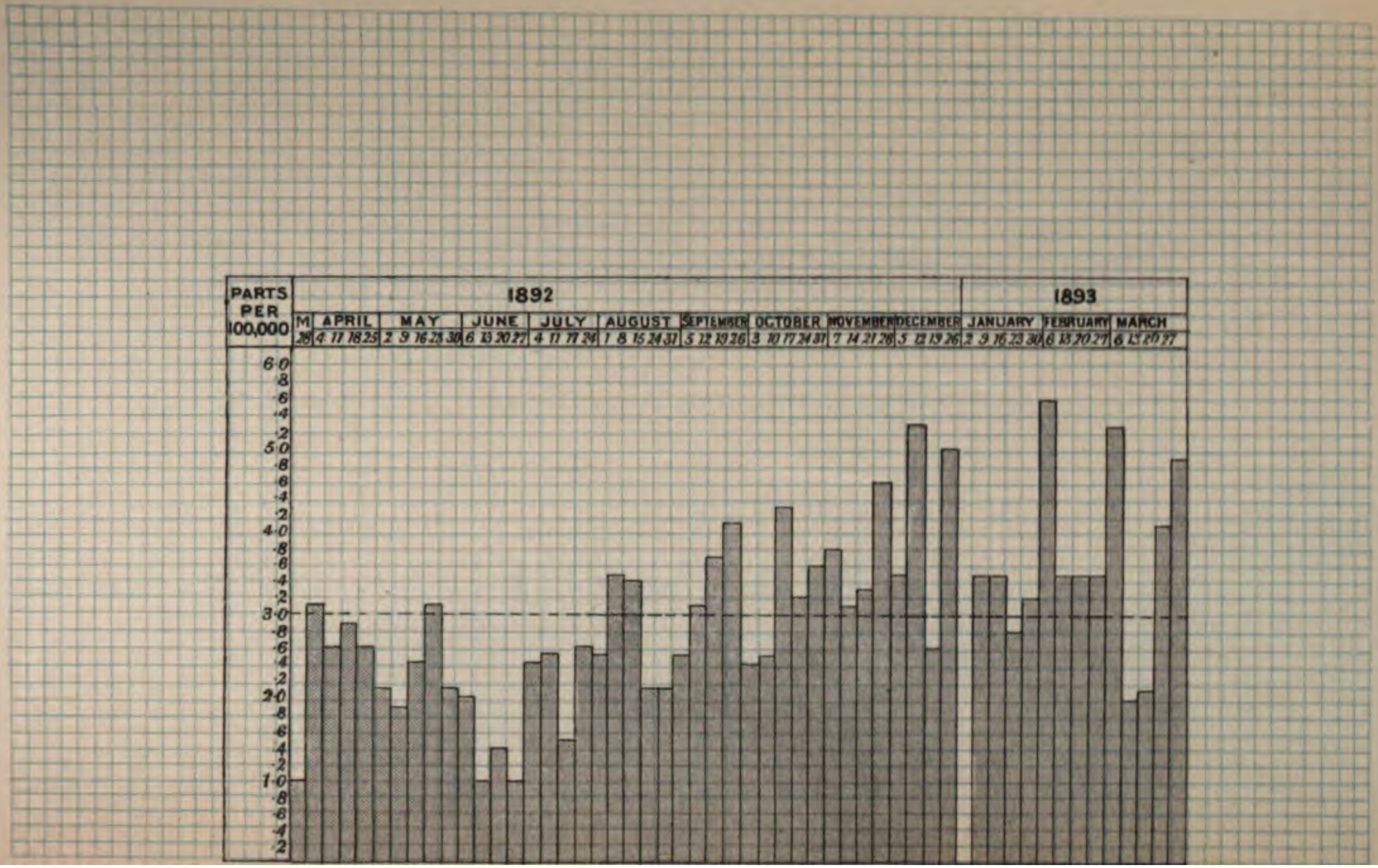
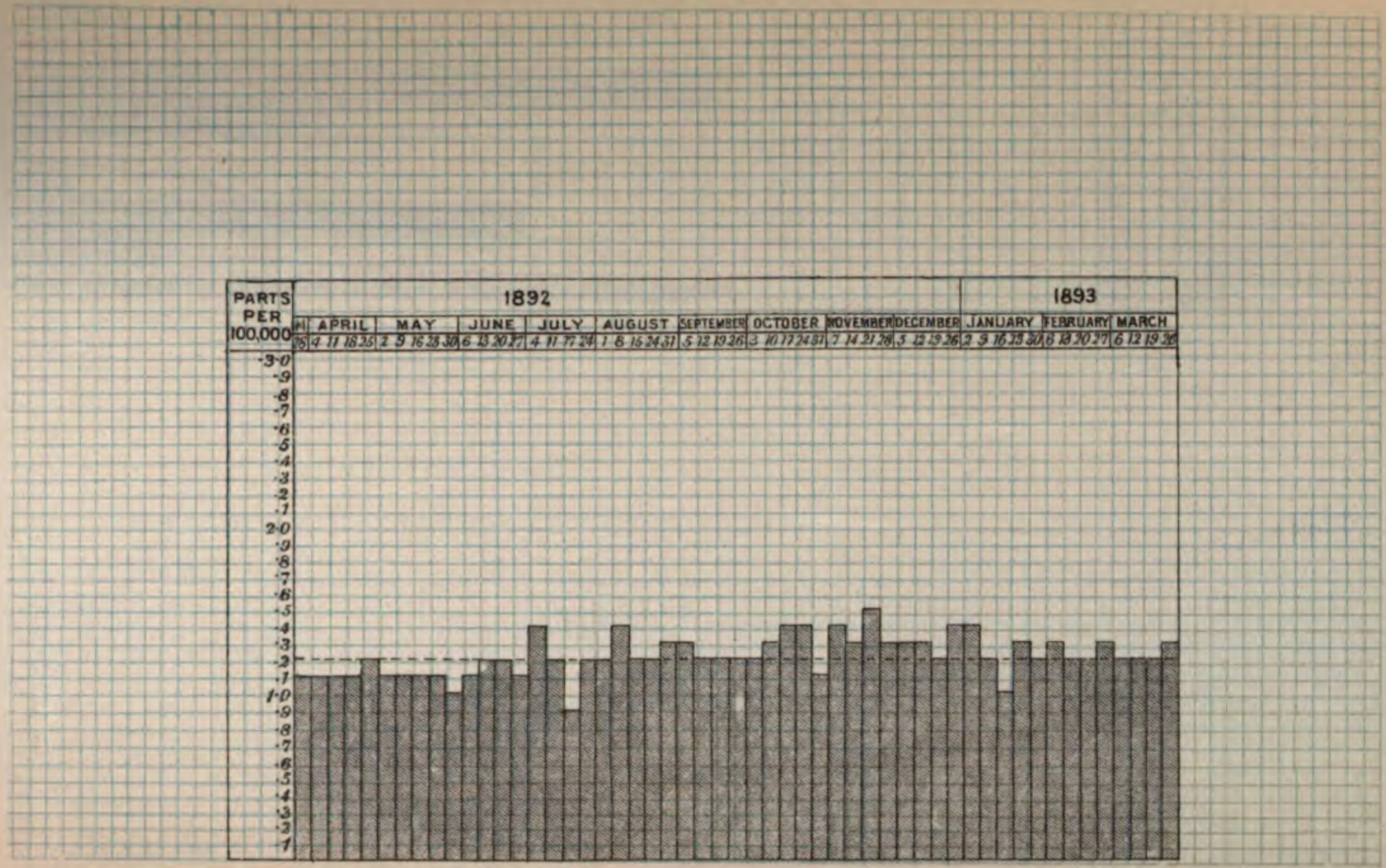
## DIAGRAM 45.

SHOWING THE RESULTS AS REGARDS **HARDNESS** OF THE CHEMICAL EXAMINATION OF THE WATER OF **BENTHAM BRIGHT SYKE STREAM.**



EXAMINATION

OF THE WATER OF BENTHAM BRIGHT SYKE STREAM



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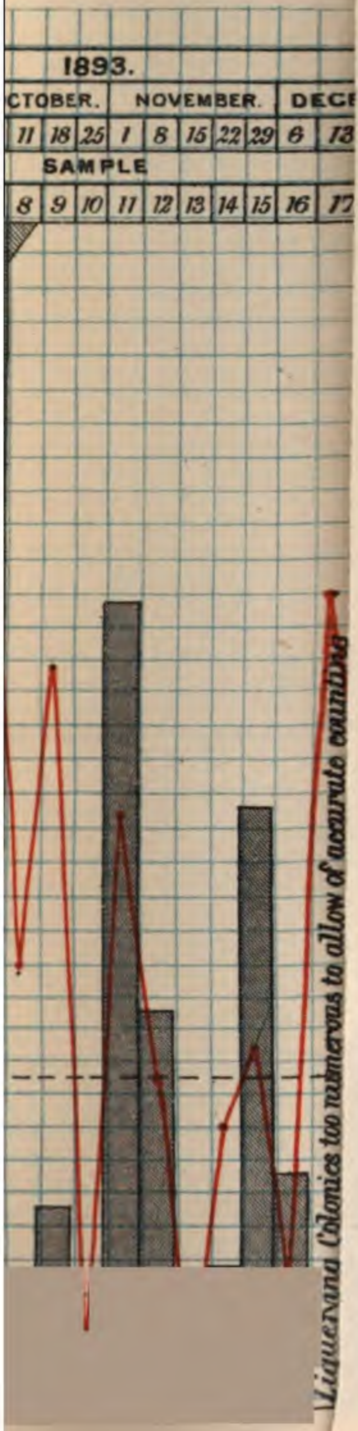

# PART II.

## RESULTS OF SURVEY OF MOORLAND GATHERING GROUNDS IN LANCASHIRE AND YORKSHIRE.

# Part II.—Results of Survey of Moorland Gathering Grounds in Lancashire and Yorkshire.

## SECTION I.—INTRODUCTORY.

This part of the report contains an account of the results of the inspection of the chief moorland gathering grounds in Yorkshire and Lancashire. Twenty-three waterworks were visited (11 in Lancashire and 12 in Yorkshire), and in each case a survey was made of their respective gathering grounds; the chief object being to ascertain the physical characters of the different drainage areas, and the chemical quality of the various waters as regards their *reaction, quâ* acidity, and their *action on lead.*

Previous to this inquiry it was known that towns supplied with moorland water sometimes suffered from epidemics of lead poisoning, but the reason why some towns so supplied escaped and others were seriously affected was by no means clear. In the case of Sheffield, however, it had been shown that the portion of the town affected with lead poisoning received its supply from the "high level" service, whereas the rest of the town was supplied with water from the "low level" supply. And it had been found that the former water was acid and the latter neutral, and this difference in the reaction of the two waters was attributed to a difference in the physical characters of the "high" and "low" level gathering grounds. Subsequently, the "high level" supply was treated with lime, which neutralised the acidity, and lead poisoning was no longer complained of. But while from these and other observations it had come to be recognised that acid moorland waters dissolved lead, and further that acidity, to which the water owed its plumbo-solvent ability, was probably associated with a peaty origin, the antecedent cause of the acidity of moorland waters had not been established on a basis of broad observation.

Moreover, no attempt had been made properly to investigate the quality as regards acidity and ability to act upon lead of the *different "kinds"* of water met with on moorland gathering grounds: to differentiate, for example, spring water, water draining from peaty soil or lying stagnant in peaty pools, and "mixed" spring and surface water. Neither had any work been done in the direction of comparing the physical characters of a number of different moorland gathering grounds in respect of the different quality of the water supplied by them.

In Part I. I have shown how, at the commencement of the inqui the gathering ground of Burnmoor was selected as affording a number typical illustrations of the different "kinds" of water usually yiel by moorland gathering grounds and kept under continuous observatio during a number of years.

The general results of this part of the inquiry up to 1894 were se out in Mr. Power's memorandum "On the causes of Lead Poisoning,' published in that year,* and further data have been given i Part I. of this report. They showed that *spring water* wa neutral, free from plumbo-solvent action, and possessed of some acid-neutralising ability; whereas *peaty water* was acid, and dissolved lead to an extent chiefly dependent on the amount of acidity. Further, it was shown that the action on lead was not to be associated with any observed chemical condition other than acidity, as, for example, the amount of organic matter, dissolved oxygen, oxidised nitrogen, &c. It has been shown that *peat* when moist is itself invariably acid, and it has been indicated that a water when it has "left" the peat has completed its history so far as acquisition of acidity is concerned. This circumstance of acidity arising in, and determined by the peat itself gave rise to a prolonged series of experiments. One direction these experiments took was to ascertain whether a mixture of peat bacteria could, when added to and grown in a neutral sterile decoction *made solely* from peat, give rise to acidity and plumbo-solvent ability of the liquid. It has already been stated that the result was affirmative, and that pure cultures of certain bacteria isolated from peat could effect a similar change in peat decoction. Here then was an explanation, although not necessarily the right or only one, of the antecedent cause of the acidity of moorland waters. Another direction the experiments took was determining the effect of removing peat from various gathering grounds and placing it in the laboratory under conditions resembling as closely as possible those on the moors as regards the relation of the peat to the rainfall. Thus artificial peat pools were constructed and neutral water was filtered through peat both continuously and also intermittently. The results were all alike in one respect, and showed that a small amount of peat can render acid a relatively large bulk of neutral water.

The results of these and of numerous other experiments led to my being instructed to make surveys of the chief moorland gathering grounds in Yorkshire and Lancashire. For it was manifestly of great importance to apply the knowledge gained at Burnmoor to other gathering grounds, and to see whether the information gained there was to be regarded as of general or only of local value. As a matter of fact, prior to the actual commencement of work at Burnmoor, a scheme had been formulated which took note of this very circumstance, namely, the necessity of supplementing and extending the information which it was anticipated would be obtained "locally" at Burnmoor, by careful inspection of the physical characters of other gathering grounds in relation to the quality of water supplied by them, and of comparing the results obtained on one area with those of other and quite separate areas.

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* Report of the Medical Officer, Local Government Board, Lead Poisoning by Moorland Waters.

The following is a list, alphabetically arranged, of the waterworks of which surveys were made:—

1. Ashton-under-Lyne, Stalybridge, and Dukinfield (District) Waterworks Joint Committee; Lancashire.
2. Bacup Corporation Waterworks; Lancashire.
3. Barnsley Corporation Waterworks; Yorkshire.
4. Barrow-in-Furness Corporation Waterworks; Lancashire.
5. Batley Corporation Waterworks; Yorkshire.
6. Blackburn Corporation Waterworks; Lancashire.
7. Bolton Corporation Waterworks; Lancashire.
8. Bradford Corporation Waterworks; Yorkshire.
9. Burnley Corporation Waterworks; Lancashire.
10. Colne Waterworks; Lancashire.
11. Dewsbury and Heckmondwike Water Board; Yorkshire.
12. Halifax Corporation Waterworks; Yorkshire.
13. Huddersfield Corporation Waterworks; Yorkshire.
14. Keighley Corporation Waterworks; Yorkshire.
15. Leeds Corporation Waterworks; Yorkshire.
16. Morley Corporation Waterworks; Yorkshire.
17. Nelson Corporation Waterworks; Lancashire.
18. Oldham Corporation Waterworks; Lancashire.
19. Preston Corporation Waterworks; Lancashire.
20. Rochdale Corporation Waterworks; Lancashire.
21. Sheffield Corporation Waterworks; Yorkshire.
22. Shipley (Eldwick) Waterworks; Yorkshire.
23. Wakefield Corporation Waterworks; Yorkshire.

Of these 23 waterworks, 11 are situated in Lancashire and 12 in Yorkshire.

Generally speaking, in each survey, general information is given under the heading:—

"Source of the water supply and general description of the waterworks," followed by special notes:—

(*a*.) On the characters of the gathering ground.

(*b*.) On conditions found to exist on the gathering ground on the date (or dates) of inspection.

(*c*.) On the results yielded by the chemical examination of the waters in reference to the observed characters of the gathering ground.

### *Source of the Water Supply and General Description of the Waterworks.*

The information grouped under the above heading was in each case obtained chiefly as a result of personal inspection of the waterworks, but also through the use of notes and statistics courteously supplied by the various waterworks officials.* I ought here to observe that while I have reason to believe that on several of the waterworks surveyed the supply is now obtained under the same conditions that existed at the date or dates of my inspection, it is likely that in some instances changes have been made by the water authority in certain of these conditions during the interval between my visit and the date of this report.

The method followed in grouping together the various facts obtained under this head has varied somewhat in different cases. Usually, however, I have described in a few words the source of the water, *e.g.*, whether from moorland or upland gathering grounds or from springs; its situation; and its distance from the chief area of supply. Then commonly follows a more detailed description of the arrangements for collecting the water, having reference, among other things, to the storage reservoirs, the inlet streams to the reservoirs, the arrangements, if any, for excluding storm water from the waterworks, the filtration or "treatment" of the water, and generally the mode of distribution of the water.

Next are given statistical notes on the waterworks. These comprise, as a rule, the following data:—The average annual rainfall on the gathering ground; its chief area of supply; the capacity, depth, superficial area, and height above Ordnance datum of the reservoirs; the consumption of water; the size of the drainage area (or areas); the daily or weekly rainfall on the gathering ground during the month *preceding the date of inspection.*

With regard to the information given in the special notes:—

### (*a.*) *On the Character of the Gathering Grounds.*

The notes under this heading deal with a variety of facts. In general, reference has in each instance been made to the physical characters of the gathering ground; to the distribution of peat; to the nature of the vegetation; to the kind of rock underlying the surface soil; to the drainage from the soil—whether slow or rapid; to the amount of spring water relative to the amount of surface water; to the opportunities of rain water stagnating in peaty, mossy, and marshy places; to the character of the beds of the feeding streams; to the amount of denudation of the surface soil; and to the nature of the slopes of the hills on the gathering area.

### (*b.*) *On conditions found to exist on the Gathering Ground on the Date of Inspection.*

Under this heading will be found a description of the conditions existing on each of the separate gathering grounds at the *actual date of inspection*, and it is to be specially noted that the chemical state of the moorland waters varies from time to time, so that what is true on one occasion may not necessarily hold good at another. Most particularly is this the case as regards the reaction of the waters, and as the rainfall in this connexion is of the utmost importance, I have in each instance stated the daily or weekly rainfall prior to the date of my visit.

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* In the matter of supplying information and transmitting samples of water, thanks are due, and are here most gratefully expressed, to the medical officers of health of the various districts and the officials of the waterworks.

I have added information as to the results of the chemical testing, performed on the spot, of the various reservoirs and "feeding" streams for the reaction, *quâ* acidity, of the water contained in them. Also the results of the more detailed examination of particular waters, collected on the date of inspection, and subsequently examined in the laboratory for acidity and plumbo-solvent ability.*

### (c.) *On the Results yielded by the Chemical Examination*† *of the Waters in Reference to the observed Characters of the Gathering Grounds.*

Under this heading the attempt is made to trace a parallelism between the chemical state of the waters and the physical circumstances of the gathering ground. In this connexion the following points, among others, have been considered—namely, on the one hand, the association of acidity and plumbo-solvent ability with certain factors, such as large amount of peat and peaty water, stagnation of rain water in peat, slow rate of drainage from the soil, comparative absence of spring water, &c.; and on the other hand the evidence afforded as to association of a neutral condition of the water and freedom from plumbo-solvent ability with other factors, such as a large amount of spring water and a small amount of peat and peaty water, with a rapid and efficient surface drainage, flow of the feeding streams along sandy and rocky beds, &c.

As has been indicated, the chemical observations made in connexion with these surveys may be divided into tests made on the spot and more detailed examination carried out afterwards in the laboratory. In testing the reaction of the water on the spot an alcoholic solution of lacmoid was invariably used. This is an extremely delicate test for this purpose, the faintest trace of acid being indicated by a change of colour from the original purplish blue to a red colour. In the more detailed chemical examination the water was tested for acidity qualitatively with lacmoid and quantitatively with $\frac{n}{10}$ sodic carbonate and phenol phthalein. In many cases the "hardness" was also determined, and in all cases the plumbo-solvent ability was tested by a method allowing of quantitative comparison. Occasionally the number of microbes was estimated by the usual gelatine plate method.

It will be remembered that in the original examination of moorand waters in connexion with the Burnmoor inquiry, a considerably more extensive chemical examination was made, which comprised determination of—(*a*) Appearance in 2-foot tube; (*b*) Re-action with alcoholic solutions of cochineal, methyl orange, and lacmoid; (*c*) Residue on evaporation and loss on ignition; (*d*) Ammonia (free and albuminoid); (*e*) Oxidised nitrogen; (*f*) Oxygen absorbed from permanganate; (*g*) Chlorine; (*h*) Hardness; (*i*) Dissolved oxygen; (*j*) Iron; (*k*) Acidity (quantitatively); (*l*) Plumbo-solvency (quantitatively).

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* The latter results are recorded in each instance in tabular form at the end of each survey.

† During a considerable period of the inquiry the assistance of Mr. J. W. Tullo, B.Sc., was obtained. His services were of the greatest value, and the efficient help he rendered is here gratefully acknowledged.

A large number of determinations as regards these chemical tests, both as to one and the same water over a considerable period of time, and also as to different waters, showed conclusively not only that acidity and plumbo-solvent ability are closely related, but also that action on lead is not to be associated with any other observed chemical condition.* Hence in later experiments, of which these surveys formed a part, attention was almost wholly directed to the examination of the waters for acidity and plumbo-solvent ability.

### *Maps.*

Along with the survey reports will be found maps illustrating the information obtained on the gathering ground, as regards the re-action of the various waters. In these maps the uniform plan is adopted of colouring the streams, reservoirs, &c., red or blue, according to whether the reaction was acid or neutral. Such colouring, it is to be noted, has reference only to the conditions found to exist on the *date of inspection.* In some of the maps brown colouring is used. This indicates the distribution of the peat.

### *Erosive ability of Waters from the Gathering Grounds surveyed.*

It will be noted that no special reference is made to the "erosive" ability of the various waters. This property will be dealt with in a further report, but here it may be stated in general terms, that from the practical point of view, erosion when associated with plumbo-solvency is of considerable importance, but that erosive ability unassociated with plumbo-solvent ability is of minor importance, unless, indeed, where *bright* lead is concerned. As a matter of fact, the moorland waters of Yorkshire and Lancashire rarely erode lead unless they are at the same time acid, and even then the action is often absent, or exhibited only to a slight extent. This, however, is not true as regards all waters, and waters other than those dealt with in this report. At all events, experience has shown conclusively that it is the acid, and consequently lead-dissolving waters, which have given rise to serious epidemics of lead poisoning in the past, and not the neutral waters, which may or may not possess erosive ability.

## DESCRIPTION OF THE CHEMICAL METHODS ADOPTED IN INVESTIGATIONS OF WATER SAMPLES.

(*a.*) *Hardness.*— Clarke's soap test was used to determine the hardness.

(*b.*) *Re-action.*—Litmus paper was found to be of little use in testing the waters qualitatively for acidity. In all the experiments lacmoid solution was used as an indicator. This is an *exceedingly delicate test* in the case of peaty waters, the merest trace of acid sufficing to change the purplish-blue colour to a red colour. Methyl-orange, litmus, and cochineal solutions were found to be of small value as compared with the above. The solution is best made by dissolving 0·2 gramme of lacmoid in 100cc. of dilute alcohol (10 per cent.). A few drops added to 10cc. of the sample of water contained in a sample tube at once reveals the presence of the smallest trace of acid. It may here be repeated that moorland waters which give a neutral re-action with this indicator do not dissolve lead to any appreciable extent. Conversely, whenever a peaty water gives an acid reaction with this indicator it will also be found to possess plumbo-solvent ability.

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* Compare Mr. Power's observations on page 338, Annual Report of the Medical Officer of the Local Government Board for 1893–4, and the diagrams appended to his Memorandum.

(*c.*) *Acidity.*—Whenever a water was found to give an acid re-action with lacmoid, the amount of the acidity was determined by titrating a definite quantity of the water with a decinormal solution of sodic carbonate (5·3 grammes $Na_2CO_3$ per litre). Phenol-phthalein (0·5 gramme in 100cc. 50 per cent. alcohol) was used as an indicator, and although open to some objections, it was found that by its use comparable results were obtained. The acidity was estimated quantitatively, with the object of seeing whether the plumbo-solvent ability of a particular water from time to time, or of one water as compared with another water, varied directly with the amount of the acidity. 100cc. of the sample of water are poured into a small flask, a few drops of the indicator added, and decinormal sodium carbonate solution, contained in a burette, added drop by drop. The faintest excess of alkali shows itself by a pink colouration of the previously colourless liquid. In the tables the results are expressed as acidity in terms of cc. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100cc. of the water. In the case of a *neutral* distilled water, one, or at the most, two drops of $\frac{n}{10}$ $Na_2CO_3$ suffice to produce a pink colouration in 100cc. with this indicator.

(*d.*) *Plumbo-solvency.*—In determining the plumbo-solvent properties of the various waters, the following process was adopted (*see* Diagram A):—

A glass tube (A) drawn out at one end (B), and about $\frac{3}{4}$-inch in diameter and 2 ft. long was held in a clamp with the tapered end downwards. To this lower end (B) a piece of rubber tubing (C) was attached. The other end of the rubber tubing was connected to one end of a U-shaped glass tube (D). The other end of the U tube (D) was dipped into the sample of water contained in a vessel (E) placed on a shelf some feet above the level of the burette. Washed lead shot which had been specially made for the purpose, and which contained no arsenic or other ingredient of a hardening nature was measured into a 50cc. measure. A small piece of muslin (F) was shoved down to the foot of the big glass tube (A), and then the shot (G) were poured into the tube, occupying about 18 inches of its length. The open end of the tube was then fitted with a small rubber bung (H) containing a thin piece of glass tubing bent twice (I and J) at right angles, with a stop-cock (K) between the two bends. Next the rubber tubing (C) was disconnected from the tapered end (B) and suction applied. As soon as the syphon was started a clip (L) was applied, and the tubing again connected with the tube (A) containing the shot. The clip was then removed and the water allowed to filter upwards through the shot (G) along the angled tube (IKJ), and so into a 50 cc. Nessler tube (M). The water was collected in successive lots of 50cc. and tested for the presence of lead with ammonium sulphide. By a previous blank experiment it was ascertained how far the stop-cock (K) had to be turned so as to allow the water to filter at the rate of 3 mins per 50cc. of water collected. This having been done the stop-cock (K) was fixed in position with sealing wax. The amount of lead was estimated by colour-titration, the standard solution of lead acetate (1·66 grms. per litre) being of such a strength that 1 cc. was equivalent to 1 mgrm. of lead. The experiments were carried out in a comparative manner, and the precaution was taken of using fresh shot for each determination, the old shot being thrown aside lest its continued use should introduce a possible source of error.

DIAGRAM A.

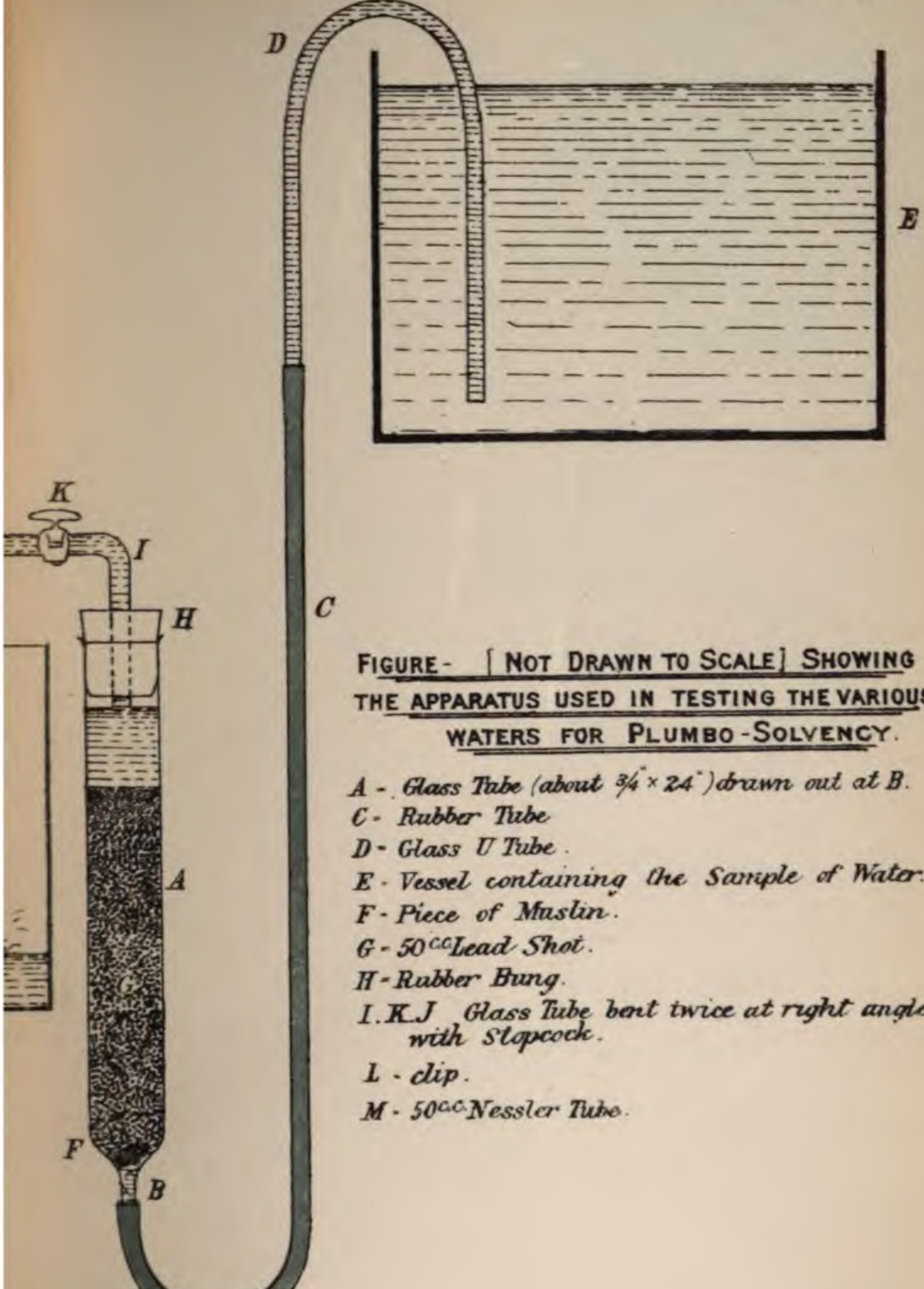

FIGURE - [NOT DRAWN TO SCALE] SHOWING THE APPARATUS USED IN TESTING THE VARIOUS WATERS FOR PLUMBO-SOLVENCY.

*A - Glass Tube (about ¾" × 24") drawn out at B.*
*C - Rubber Tube*
*D - Glass U Tube.*
*E - Vessel containing the Sample of Water.*
*F - Piece of Muslin.*
*G - 50 c.c. Lead Shot.*
*H - Rubber Bung.*
*I. K. J Glass Tube bent twice at right angles with Stopcock.*
*L - clip.*
*M - 50 c.c. Nessler Tube.*

E Weller & Graham

moorland and the water from certain springs, one of which is known as Wicken Spring, but which, for the purposes of description, may be classed together as the Wicken Springs. The bye-wash is continued down the west side of Lower Swineshaw and receives above the outlet water from Higher Swineshaw, and opens lower down into Lower Swineshaw. Beyond Lower Swineshaw it joins the natural bed of the stream in Swineshaw Valley, and the water in this stream discharges into the upper end of Brushes Reservoir, or can be carried by a further continuation of the channel past Brushes to Walker Wood Compensation Reservoir. Taking the reservoirs in order from above downwards, Higher Swineshaw Reservoir is situated at a height of 957 feet above sea level, and is supplied with water from the following sources: Wicken Brook opens into the north-west angle of Higher Swineshaw, and it drains a large area of moorland, but receives besides surface peaty water a considerable amount of spring water. Along the north side of the reservoir are a number of springs—Wicken Springs. These are piped together into a common channel which opens into the bye-wash and can be turned from thence back into the reservoir, or carried downwards to Lower Swineshaw or to Brushes Reservoir. Swineshaw Brook, the main stream on the gathering ground, drains a considerable tract of moorland. It opens into the north-east angle of the reservoir, or can be turned down the bye-wash. A small peat drain opens into the west side of the reservoir, and a number of small streams draining very peaty land (Boar Flat) open into the bye-wash on the opposite side of the reservoir. Lower Swineshaw is situated at a height of 768 feet above sea level. It can be supplied either with the outlet water from Higher Swineshaw, or by means of the bye-wash with the water from the Wicken Springs and Swineshaw Brook. It also receives the water from three small streams on the east side. The water from Lower Swineshaw is used for the supply of the town of Mossley and a portion of Stalybridge. Brushes Reservoir is situated at a height of 649 feet above sea level, and together with the water from the Greenfield Valley supplies Ashton—Stalybridge and Dukinfield being supplied from Swineshaw only. A small amount of water, chiefly from hillside springs, enters the south side of the reservoir, but the main source of supply is from the stream which naturally drains this valley and into which the bye-wash opens after leaving Lower Swineshaw. This stream enters the upper end of Brushes Reservoir, and the water in it can be diverted down the continuation of the bye-wash past Brushes to Walker Wood Compensation Reservoir. It remains to note, however, from what sources the above stream is fed. Between the point of entrance of the bye-wash and Brushes Reservoir, a certain amount of water drains from the southerly hill slopes to the east of Brushes into this stream. This water together with the water flowing into the south side of the reservoir is not, however, sufficient to feed Brushes. There is a considerable leakage from Lower Swineshaw Reservoir and this water enters the stream. Further, the water from Higher Swineshaw can be utilised by means of the bye-wash, and it is to be noted that it is possible to supply Brushes from the springs before mentioned, and Swineshaw Brook either mixed or unmixed with Higher Swineshaw water. It does not appear to be the custom to supply Brushes with Lower Swineshaw water, and the chief reason is stated to be that the leakage from Lower Swineshaw makes it undesirable to keep the water in that reservoir at its proper level. Walker Wood Reservoir which is used only for compensation purposes, is supplied with flood water and the overflow from the above reservoirs. In conclusion it is to be noted that Ashton is supplied with the mixed water from Brushes and Yeoman Hey Reservoirs, or from the springs in the Greenfield Valley. Mossley is supplied from Lower

### *Daily Rainfall on the Swineshaw Gathering Ground from August* 25, 1895, *to September* 25, 1895, *inclusive.*

| 1895. | Rainfall. | 1895. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| August 25 | 0·05 | September 11 | 0·60 |
| „ 26 | 1·40 | „ 12 | — |
| „ 27 | 0·90 | „ 13 | — |
| „ 28 | 0·02 | „ 14 | — |
| „ 29 | 0·08 | „ 15 | — |
| „ 30 | — | „ 16 | — |
| „ 31 | — | „ 17 | — |
| September 1 | — | „ 18 | — |
| „ 2 | — | „ 19 | — |
| „ 3 | 0·26 | „ 20 | — |
| „ 4 | 0·45 | „ 21 | — |
| „ 5 | 0·04 | „ 22 | — |
| „ 6 | 0·50 | „ 23 | — |
| „ 7 | — | „ 24 | — |
| „ 8 | — | „ 25 | — |
| „ 9 | — | | |
| „ 10 | 0·10 | Total | 4·40 |

### *Daily Rainfall on the Greenfield Gathering Ground from October* 1, 1894, *to November* 1, 1894, *inclusive.*

Yeoman Hey gauge.

| 1894. | Rainfall. | 1894. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| October 1 | — | October 18 | 0·1 |
| „ 2 | — | „ 19 | — |
| „ 3 | — | „ 20 | 2·5 |
| „ 4 | — | „ 21 | 0·1 |
| „ 5 | 0·1 | „ 22 | — |
| „ 6 | 0·2 | „ 23 | 0·2 |
| „ 7 | 0·1 | „ 24 | 0·7 |
| „ 8 | — | „ 25 | 1·0 |
| „ 9 | 0·4 | „ 26 | 1·0 |
| „ 10 | — | „ 27 | 0·1 |
| „ 11 | — | „ 28 | 0·3 |
| „ 12 | — | „ 29 | 0·5 |
| „ 13 | — | „ 30 | — |
| „ 14 | — | „ 31 | 0·1 |
| „ 15 | — | November 1 | 0·2 |
| „ 16 | — | | |
| „ 17 | — | Total | 7·6 |

# SECTION II.:—PARTICULARS RESPECTING EACH OF THE TWENTY-THREE GATHERING GROUNDS SURVEYED.

## Survey No. 1.[*]

### [†] ASHTON-UNDER-LYNE, STALYBRIDGE, AND DUKINFIELD (DISTRICT) WATERWORKS JOINT COMMITTEE.

### Source of the Water Supply and General Description of the Waterworks.

The water supply is obtained from high gathering grounds at Swineshaw and Greenfield, situate about 5 miles from the town of Mossley and 2½ and 8 miles from Ashton respectively.

*Greenfield Supply.*[‡]—At present (1897) there is a single reservoir on this gathering ground, situated at a height of 768 feet above ordnance datum, which receives the drainage from the Greenfield Valley, and is known as the Yeomen Hey Reservoir. The main source of supply to this reservoir is from Greenfield Brook, which drains a considerable tract of moorland. The water draining from the moors on the east side of the reservoir is excluded from the waterworks, and is carried by a tunnel down the valley into Greenfield Brook below the reservoir. The water draining to the reservoir on the west side is chiefly spring water. In connexion with each of the larger streams on this side of the reservoir is a chamber fitted with a mechanical contrivance ("leap" weir), which permits the dry weather flow to drop through an opening leading to a common channel connecting the various streams, but which prevents flood water from so entering, owing to its greater velocity carrying it over and beyond the opening leading to this channel, the water passing instead into the reservoir. The water in this channel, common to the various streams, is led into settling and straining tanks, and can be turned therefrom either directly into the reservoir or into the mains leading to Ashton, Mossley, and Saddleworth. It follows, from the above, that the streams on the west side flow during floods into the reservoir, and, under ordinary conditions of the rainfall, discharge into a common channel leading to settling and straining tanks, from whence the mixed water can be turned into the reservoir or passed directly into consumption. Two small ferruginous springs discharge the one into the north-east and the other into the south-east angles of Yeoman Hey Reservoir. A small portion of the lower lying levels of the town of Mossley is supplied with the water from this valley, but nearly all the water is used for the supply of Ashton and Saddleworth.

*Swineshaw Supply.*—There are four reservoirs on this gathering ground, Higher Swineshaw, Lower Swineshaw, Brushes, and Walker Wood; the latter being used only for compensation purposes. A bye-wash runs alongside the reservoirs and can be used either to carry storm and overflow water to compensation, or to convey water from a higher to a lower reservoir. It is connected above with Swineshaw Brook, and runs along the east side of Higher Swineshaw, receiving on its way the overflow water from the reservoir, as well as the drainage from peaty moorland and the water from certain springs, one of which is known as Wicken Spring, but which, for the purposes of description, may be classed together as the Wicken Springs. The bye-wash is continued down the west side of Lower Swineshaw and receives above the outlet water from Higher Swineshaw, and opens lower down into Lower Swineshaw. Beyond Lower Swineshaw it joins the natural bed of the stream in Swineshaw Valley, and the water in this stream discharges into the upper end of Brushes Reservoir, or can be carried by a further continuation of the channel past Brushes to Walker Wood Compensation Reservoir. Taking the reservoirs in order from above downwards, Higher Swineshaw Reservoir is situated at a height of 957 feet above sea level, and is supplied with water from the following sources: Wicken Brook opens into the north-west angle of Higher Swineshaw, and it drains a large area of moorland, but receives besides surface peaty water a considerable amount of spring water. Along the north side of the reservoir are a number of springs—Wicken Springs. These are piped together into a common channel which opens into the bye-wash and can be turned from thence back into the reservoir, or carried downwards to Lower Swineshaw or to Brushes Reservoir. Swineshaw Brook, the main stream on the gathering ground, drains a considerable tract of moorland. It opens into the north-east angle of the reservoir, or can be turned down the bye-wash. A small peat drain opens into the west side of the reservoir, and a number of small streams draining very peaty land (Boar Flat) open into the bye-wash on the opposite side of the reservoir. Lower Swineshaw is situated at a height of 768 feet above sea level. It can be supplied either with the outlet water from Higher Swineshaw, or by means of the bye-wash with the water from the Wicken Springs and Swineshaw Brook. It also receives the water from three small streams on the east side. The water from Lower Swineshaw is used for the supply of the town of Mossley and a portion of Stalybridge. Brushes Reservoir is situated at a height of 649 feet above sea level, and together with the water from the Greenfield Valley supplies Ashton—Stalybridge and Dukinfield being supplied from Swineshaw only. A small amount of water, chiefly from hillside springs, enters the south side of the reservoir, but the main source of supply is from the stream which naturally drains this valley and into which the bye-wash opens after leaving Lower Swineshaw. This stream enters the upper end of Brushes Reservoir, and the water in it can be diverted down the continuation of the bye-wash past Brushes to Walker Wood Compensation Reservoir. It remains to note, however, from what sources the above stream is fed. Between the point of entrance of the bye-wash and Brushes Reservoir, a certain amount of water drains from the southerly hill slopes to the east of Brushes into this stream. This water together with the water flowing into the south side of the reservoir is not, however, sufficient to feed Brushes. There is a considerable leakage from Lower Swineshaw Reservoir and this water enters the stream. Further, the water from Higher Swineshaw can be utilised by means of the bye-wash, and it is to be noted that it is possible to supply Brushes from the springs before mentioned, and Swineshaw Brook either mixed or unmixed with Higher Swineshaw water. It does not appear to be the custom to supply Brushes with Lower Swineshaw water, and the chief reason is stated to be that the leakage from Lower Swineshaw makes it undesirable to keep the water in that reservoir at its proper level. Walker Wood Reservoir which is used only for compensation purposes, is supplied with flood water and the overflow from the above reservoirs. In conclusion it is to be noted that Ashton is supplied with the mixed water from Brushes and Yeoman Hey Reservoirs, or from the springs in the Greenfield Valley. Mossley is supplied from Lower

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[*] The Surveys are arranged alphabetically and bear no relation to the dates of inspection.

[†] This is a joint committee, combining five local authorities incorporated by Act of Parliament in 1870, and in which the Mossley Corporation possess a one ninth share of the capital, in virtue of which they are represented on the Committee of Management by two members of the Town Council, appointed by that body.

[‡] It is intended to construct another reservoir in the Greenfield Valley in the immediate future.

Swineshaw, but a small portion of the low lying part of the town can be supplied with the Greenfield water. None of the water is submitted to any process of filtration; prior to December 1894, no treatment of the water was adopted, but since then the water from Higher Swineshaw, before entering Lower Swineshaw, has been treated with whiting, (about 1¼ grains to the gallon), and this treatment has been continued up to the present time, 1897.

The following notes on the waterworks are of interest:—

### *Rainfall.*

Average yearly rainfall in Mossley:—No record.

" " " on Swineshaw gathering ground:—Average of 10 years, 47·56.

" " " on Greenfield gathering ground (Yeoman Hey gauge):—48·9.

### *Capacity, &c., of the Reservoirs.*

| Name. | Capacity. | Depth. | Area. |
|---|---|---|---|
| | Gallons. | Feet. | |
| Yeoman Hey - - | 208,000,000 | 65 | About 28 acres. |
| Higher Swineshaw - | 168,908,000 | 53 | ,, 24¾ ,, |
| Lower Swineshaw - - | 55,500,000 | 33 | ,, 11½ ,, |
| Brushes - - - | 52,165,000 | 44 | ,, 7 ,, |
| Walker Wood - - | 202,084,000 | 61 | ,, 25¾ ,, |

### *Consumption of Water.*

About 30 million gallons weekly including compensation of 10,700,000 gallons weekly.

### *Drainage Areas.*

| | |
|---|---|
| Greenfield - - - - | 1,170 acres. |
| Swineshaw - - - | 1,300 ,, |

### *Daily Rainfall on the Swineshaw Gathering Ground from August 12, 1894, to September 12, 1894, inclusive.*

| 1894. | Rainfall. | 1894. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| August 12 - - | 0·20 | August 29 - - | — |
| ,, 13 - - | 0·06 | ,, 30 - - | — |
| ,, 14 - - | 0·31 | ,, 31 - - | — |
| ,, 15 - - | 0·32 | September 1 - - | — |
| ,, 16 - - | 0·02 | ,, 2 - - | — |
| ,, 17 - - | — | ,, 3 - - | — |
| ,, 18 - - | 0·41 | ,, 4 - - | 0·06 |
| ,, 19 - - | 0·75 | ,, 5 - - | 0·32 |
| ,, 20 - - | 0·10 | ,, 6 - - | — |
| ,, 21 - - | 0·07 | ,, 7 - - | — |
| ,, 22 - - | — | ,, 8 - - | — |
| ,, 23 - - | 0·09 | ,, 9 - - | — |
| ,, 24 - - | — | ,, 10 - - | — |
| ,, 25 - - | 0·32 | ,, 11 - - | — |
| ,, 26 - - | 0·02 | ,, 12 - - | — |
| ,, 27 - - | 0·04 | | |
| ,, 28 - - | — | Total - - | 3·09 |

### *Daily Rainfall on the Swineshaw Gathering Ground from August* 1895, *to September* 25, 1895, *inclusive.*

| 1895. | Rainfall. | 1895. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| August 25 | 0·05 | September 11 | 0·60 |
| „ 26 | 1·40 | „ 12 | — |
| „ 27 | 0·90 | „ 13 | — |
| „ 28 | 0·02 | „ 14 | — |
| „ 29 | 0·08 | „ 15 | — |
| „ 30 | — | „ 16 | — |
| „ 31 | — | „ 17 | — |
| September 1 | — | „ 18 | — |
| „ 2 | — | „ 19 | — |
| „ 3 | 0·26 | „ 20 | — |
| „ 4 | 0·45 | „ 21 | — |
| „ 5 | 0·04 | „ 22 | — |
| „ 6 | 0·50 | „ 23 | — |
| „ 7 | — | „ 24 | — |
| „ 8 | — | „ 25 | — |
| „ 9 | — | | |
| „ 10 | 0·10 | Total | 4·40 |

### *Daily Rainfall on the Greenfield Gathering Ground from October* 1894, *to November* 1, 1894, *inclusive.*

Yeoman Hey gauge.

| 1894. | Rainfall. | 1894. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| October 1 | — | October 18 | 0·1 |
| „ 2 | — | „ 19 | — |
| „ 3 | — | „ 20 | 2·5 |
| „ 4 | — | „ 21 | 0·1 |
| „ 5 | 0·1 | „ 22 | — |
| „ 6 | 0·2 | „ 23 | 0·2 |
| „ 7 | 0·1 | „ 24 | 0·7 |
| „ 8 | — | „ 25 | 1·0 |
| „ 9 | 0·4 | „ 26 | 1·0 |
| „ 10 | — | „ 27 | 0·1 |
| „ 11 | — | „ 28 | 0·3 |
| „ 12 | — | „ 29 | 0·5 |
| „ 13 | — | „ 30 | — |
| „ 14 | — | „ 31 | 0·1 |
| „ 15 | — | November 1 | 0·2 |
| „ 16 | — | | |
| „ 17 | — | Total | 7·6 |

### *Daily Rainfall on the Swineshaw Gathering Ground from October* 1, 1894, *to November* 1, 1894, *inclusive.*

| 1894. | Rainfall. | 1894. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| October 1 | — | October 18 | — |
| ,, 2 | — | ,, 19 | — |
| ,, 3 | — | ,, 20 | 1·62 |
| ,, 4 | — | ,, 21 | 0·05 |
| ,, 5 | 0·05 | ,, 22 | — |
| ,, 6 | 0·10 | ,, 23 | 0·14 |
| ,, 7 | 0·05 | ,, 24 | 1·02 |
| ,, 8 | — | ,, 25 | 1·51 |
| ,, 9 | 0·41 | ,, 26 | 0·70 |
| ,, 10 | 0·09 | ,, 27 | 0·07 |
| ,, 11 | — | ,, 28 | 0·16 |
| ,, 12 | — | ,, 29 | 0·91 |
| ,, 13 | — | ,, 30 | 0·03 |
| ,, 14 | | ,, 31 | 0·09 |
| ,, 15 | 0·01 | November 1 | 0·13 |
| ,, 16 | — | | |
| ,, 17 | — | Total | 7·14 |

### *Weekly Rainfall on the Swineshaw Gathering Ground, from October* 1893, *to June* 1896.

| Date. | Rainfall. | Date. | Rainfall. |
|---|---|---|---|
| 1893. | Inches. | 1894. | Inches. |
| October 7 | 0·98 | April 28 | 0·57 |
| ,, 14 | 1·32 | May 5 | 0·62 |
| ,, 21 | 0·15 | ,, 12 | 1·24 |
| ,, 28 | 1·10 | ,, 19 | 0·18 |
| November 4 | 1·05 | ,, 26 | 0·15 |
| ,, 11 | 0·23 | June 2 | 0·87 |
| ,, 18 | 0·44 | ,, 9 | 2·74 |
| ,, 25 | 2·01 | ,, 16 | 1·07 |
| December 2 | 0·68 | ,, 23 | 0·33 |
| ,, 9 | 0·95 | ,, 30 | 0·15 |
| ,, 16 | 1·51 | July 7 | 0·24 |
| ,, 23 | 1·54 | ,, 14 | 0·48 |
| ,, 30 | 0·57 | ,, 21 | 2·30 |
| | | ,, 28 | 0·96 |
| 1894. | | August 4 | 2·54 |
| January 6 | 0·05 | ,, 11 | 1·40 |
| ,, 13 | 0·46 | ,, 18 | 1·32 |
| ,, 20 | 1·47 | ,, 25 | 1·33 |
| ,, 27 | 1·07 | September 1 | 0·06 |
| February 3 | 1·10 | ,, 8 | 0·38 |
| ,, 10 | 2·66 | ,, 15 | Nil. |
| ,, 17 | 1·13 | ,, 22 | 0·45 |
| ,, 24 | 0·48 | ,, 29 | 0·19 |
| March 3 | 2·14 | October 6 | 0·15 |
| ,, 10 | 2·64 | ,, 13 | 0·55 |
| ,, 17 | 1·19 | ,, 20 | 1·63 |
| ,, 24 | 0·04 | ,, 27 | 3·49 |
| ,, 31 | 0·09 | November 3 | 1·50 |
| April 7 | 0·51 | ,, 10 | 1·40 |
| ,, 14 | 0·43 | ,, 17 | 1·28 |
| ,, 21 | 0·63 | ,, 24 | 0·19 |

| Date. | Rainfall. |
|---|---|
| 1894. | Inches. |
| December 1 | 0·05 |
| „ 8 | 0·36 |
| „ 15 | 1·34 |
| „ 22 | 2·41 |
| „ 29 | 0·44 |
| 1895. | |
| January 5 | 0·28 |
| „ 12 | Nil. |
| „ 19 | 1·04 |
| „ 26 | 1·22 |
| February 2 | Nil. |
| „ 9 | Nil. |
| „ 16 | Nil. |
| „ 23 | 0·05 |
| March 2 | 0·83 |
| „ 9 | 0·51 |
| „ 16 | 0·17 |
| „ 23 | 1·50 |
| „ 30 | 1·95 |
| April 6 | 1·16 |
| „ 13 | Nil. |
| „ 20 | 0·26 |
| „ 27 | 0·74 |
| May 4 | 0·52 |
| „ 11 | Nil. |
| „ 18 | 0·05 |
| „ 25 | 0·71 |
| June 1 | 0·46 |
| „ 8 | 0·05 |
| „ 15 | 0·18 |
| „ 22 | 0·06 |
| „ 29 | 2·20 |
| July 6 | 1·01 |
| „ 13 | 0·91 |
| „ 20 | 1·98 |
| „ 27 | 5·25 |
| August 3 | 0·28 |
| „ 10 | 1·34 |
| „ 17 | 1·36 |
| „ 24 | 0·31 |
| „ 31 | 2·45 |
| September 7 | 1·25 |
| „ 14 | 0·70 |
| 1895. | Inches. |
| September 21 | Nil. |
| „ 28 | Nil. |
| „ 5 | 2·24 |
| October 12 | 0·86 |
| „ 19 | 0·34 |
| „ 26 | 0·68 |
| November 2 | 0·20 |
| „ 9 | 0·59 |
| „ 16 | 1·61 |
| „ 23 | 0·49 |
| „ 30 | 0·30 |
| December 7 | 1·79 |
| „ 14 | 1·91 |
| „ 21 | 0·02 |
| „ 28 | 0·51 |
| 1896. | |
| January 4 | 0·82 |
| „ 11 | 0·10 |
| „ 18 | 1·28 |
| „ 25 | 0·46 |
| February 1 | 0·24 |
| „ 8 | 0·56 |
| „ 15 | 0·17 |
| „ 22 | 0·28 |
| „ 29 | 2·98 |
| March 7 | 2·42 |
| „ 14 | 1·02 |
| „ 21 | 1·01 |
| „ 28 | 1·64 |
| April 4 | 0·19 |
| „ 11 | 0·52 |
| „ 18 | 0·80 |
| „ 25 | 0·16 |
| May 2 | 0·70 |
| „ 9 | Nil. |
| „ 16 | Nil. |
| „ 23 | 0·82 |
| „ 30 | Nil. |
| June 6 | 0·85 |
| „ 13 | 0·17 |
| „ 20 | 0·61 |
| „ 27 | 1·09 |

## *Notes on the Characters of the Gathering Grounds.*

*Greenfield Supply* The gathering ground is entirely composed of moorland. Peat covers nearly the whole of the drainage area, but the deposits are not deep, even on the higher portions of the collecting ground, and on the slopes of the hills, the disintegrated rock underlying the peat frequently appears on the surface as sand beds. There are areas on the gathering ground covered with the growth of coarse pasture grass, and elsewhere heather is abundant. The drainage from the soil is for the most part rapid, and the slopes of the hills in many instances are very abrupt. There are but few places where the rain can stagnate in peaty soil. For a moorland gathering ground the proportion of spring water to surface water is above the average. The conditions are not so favourable towards the upper reaches of Greenfield

Brook, and on the hill-tops on the west side of the reservoir. From these places a considerable amount of surface peaty water gains access to the waterworks. The large body of spring water, however, issuing from the hill-sides to the west of Yeoman Hey is an important feature of this supply. The geological formation is millstone grit. The larger streams supplying the reservoir run on rocky and sandy beds, and as the denudation of the steep hill sides is very considerable, a large amount of disintegrated rock and sand and peaty matter is washed into the waterworks.

*Swineshaw Supply.*—This is a moorland gathering ground, but the amount of peat varies very much on different portions of the drainage area. Speaking generally, peat is most abundant superficially and in depth on the higher and flatter parts of the ground, especially in the neighbourhood of higher Swineshaw. Lower down, near Brushes, the hill slopes are very abrupt, and the peat beds are not so extensive, and are thinner.

The rock underlying the peat is millstone grit, and in the vicinity of Brushes Reservoir it appears on the surface in many places, the surface soil being here very thin. The vegetation is chiefly heather on the tops of the hills, and heather and rough pasture grass lower down. The drainage from the soil is most rapid near Brushes, where the hill sides are precipitous and the covering soil thin. It is least rapid at Higher Swineshaw, where the ground is much flatter, and where the surface soil consists of peat, which in many places is several feet in depth. A point of importance is that, although the amount of peaty water entering the waterworks is very considerable, the proportion of spring water to surface water is greater than is usually found to be the case in water supplies of moorland origin. It is uncommon to find on moors situated at such a height above sea level, so abundant a supply of spring water as is given out by the Wicken and other springs at Higher Swineshaw. There is a considerable amount of peat in the bed of the Swineshaw Reservoirs, and also a little in the bed of Brushes Reservoir.

### *Conditions found to exist on the Gathering Grounds on September* 12, 1894, *November* 1, 1894, *and September* 25, 1895.

On the first occasion, only the Swineshaw gathering ground was visited; on the second, both the Swineshaw and Greenfield; and on September 25th, 1895, the Swineshaw only. The daily rainfall for the months prior to each of the above dates is given in accompanying tables. Lacmoid was used in testing the reaction of the various waters. Laboratory experiments show that when a moorland water gives a neutral re-action with this reagent, the water practically has no plumbo-solvent ability, but that when the reaction is acid the water dissolves lead to an extent depending on the amount of acid.

On September 12th, 1894, the following results were obtained:—The water in higher and Lower Swineshaw and Brushes reservoirs was tested at various points, and the Swineshaw Reservoirs were found to be distinctly acid, and Brushes Reservoir neutral. The main inlet stream to Brushes was neutral, and the other streams (which are chiefly fed from springs) supplying this reservoir, had a similar reaction. Three small streams entering the east side of Lower Swineshaw were neutral, but the water reaching the reservoir from Higher Swineshaw was acid. Swineshaw Brook and Wicken Brook were neutral, as was also the water from each of the five Wicken Springs. A small peat drain on the west side of Higher Swineshaw was very acid, and some distinctly acid water was gaining access to the bye-wash from Boar Flat, which is a peaty expanse of moorland on the east side of Higher Swineshaw.

On November 1st, 1894, the same results were obtained, except that Swineshaw Brook and the main inlet stream to Brushes were acid instead of neutral. On this date it is to be noted that the streams were running fuller than on September 12th.

On September 25th, 1895, the same results were obtained as on September of the preceding year, with the following important exception:—Lower Swineshaw Reservoir, which was found to be acid on the two former occasions on which it was tested, was now practically neutral. This result is to be explained by the fact that since December 1894, the water supplying Lower Swineshaw from Higher Swineshaw was treated with whiting.

On November 1st, 1894, the following results were obtained in the Greenfield Valley:—The water in Yeoman Hey Reservoir was tested at various points, and it was found to be acid in reaction. Greenfield Brook was traced for some distance up its course. It was acid, and one of its main tributary feeders had a similar reaction, and when traced upwards was found to divide into two acid streams, both draining land peaty in character. The two small streams which contain chiefly ferruginous peaty water and which enter the reservoir at its north-east and south-east angles, were found to be neutral. As regards the spring water on the west side of the reservoir, all the springs were carefully tested and they were neutral in each case. The mixed spring water in the settling and straining tanks was also tested, and gave a similar result. On the above date most of this spring water was being sent direct into consumption without passing first through the reservoir.

On October 26th and 27th, 1893, Dr. S. Monckton Copeman visited the Swineshaw and Greenfield gathering grounds, acting under the direction of the Local Government Board, and in consequence of a report to the effect that lead poisoning, due to water supply, was very prevalent in the town of Mossley. The results of Dr. Copeman's tests correspond with the above. Thus he found Higher Swineshaw, Lower Swineshaw, and Yeoman Hey Reservoirs acid, and Brushes neutral. He also found that the springs in the Greenfield Valley gave, when tested with litmus paper, a neutral reaction. Dr. Copeman showed conclusively in his report that lead poisoning was prevalent only in those districts supplied with acid water from Lower Swineshaw Reservoir, and that where the neutral water from Brushes Reservoir and from the Greenfield Springs was supplied to the inhabitants, there was no lead poisoning.

Samples of water were collected for more detailed examination from the following sources:—Yeoman Hey, Brushes, Higher Swineshaw, and Lower Swineshaw Reservoirs, and from Springs No. 1, 2, and 3, to Brushes Reservoir. Samples of water were also obtained from the Wicken Springs, and further samples from the above-mentioned reservoirs. The results are given in an accompanying table, and may be briefly described as follows:—The sample of Yeoman Hey Reservoir which was collected from the side of the reservoir on September 14th, 1894, was acid, and acted appreciably on lead. The samples obtained from the "outlet," the one on February 20th, and the other on October 20th, 1894, were neutral, and free from plumbo-solvent ability. It is to be noted that on November 1st, 1894, the reservoir was tested at various points, and was found to be acid, and that Dr. Copeman obtained similar results on October 27th, 1893. It is possible that the caretaker of the waterworks may have misunderstood his instructions, and collected the neutral samples from a point near the entrance to the reservoir of the Greenfield Springs. Brushes Reservoir water—four samples—was found to be neutral, and free from action on lead. Lower Swineshaw reservoir water was distinctly acid, and acted decidedly on lead on September 14th and October 20th, 1894, but on September 26th, 1895, after the lime treatment had been in operation for a considerable time, the water was practically neutral, and free from plumbo-solvent ability.

All the samples of water from Higher Swineshaw Reservoir were distinctly acid, and possessed of considerable plumbo-solvent ability. The Brushes Springs, and Wicken Springs, and Wicken Brook were neutral. Equal parts of the water from the Wicken Springs, when mixed together, gave a neutral reaction and showed no plumbo-solvent ability. Equal parts of this mixed spring water and Higher Swineshaw water gave, when tested, a neutral reaction, and did not dissolve lead. This result is of interest, as it indicates that moorland springs are not only neutral, but possessed of some acid neutralising ability. Higher Swineshaw Reservoir water, after treatment with lime, was practically neutral and free from action on lead. It is to be noted that all the waters were very soft. It might be expected that the water derived from the Wicken Springs would be decidedly harder than the water in the reservoirs. No such great difference, however, was found to exist between the two, and this result corresponds with what has been noted on other collecting grounds having similar characters. It appears usual to find the spring water very soft on moorland gathering grounds which are situated at a great height above sea level, and where the geological formation is millstone grit. It is of interest to note that the lime treatment had the effect of sensibly hardening the water in Lower Swineshaw Reservoir.

Samples of Mossley main water were obtained at regular intervals, and over a considerable space of time. The results are given in separate tables, and will be discussed in a different section of the report. It may be stated here, however, that the results showed that Mossley was being supplied with a water possessed of acidity and plumbo-solvent ability. This was the case prior to the lime treatment. Afterwards the condition of the water improved materially in these important respects. As has been already indicated, the town of Mossley is supplied with water from Lower Swineshaw Reservoir.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in Reference to the Observed Characters of the Gathering Grounds.*

*Greenfield Supply.*—The acid condition of Yeoman Hey Reservoir water on November, 1894, is easily to be accounted for when it is remembered that Greenfield Brook the main inlet stream to the reservoir was also acid. The acidity of Greenfield Brook appears to be due to the peaty nature of the surface soil drained by it. That this supply is not more acid is to be accounted for by certain redeeming features on the drainage area. These have been already indicated, *e.g.*, the large amount of neutral spring water as well as of acid peaty water, the shallowness of the peat beds, the abrupt slopes of the hills allowing of rapid drainage, and the comparative absence of areas such as exist on so many moorland gathering grounds where the rain can saturate and lie stagnant in peaty soil, &c., &c.

It is not improbable that Greenfield Brook supplies Yeoman Hey with a neutral water during its dry weather flow, and with a very acid water during storm time. In the former case the water would be chiefly derived from hill-side springs, and in the latter case from the surface drainage of peat. In intermediate conditions of the rainfall the water is probably only slightly acid.

*Swineshaw Supply.*—The acidity of Higher Swineshaw Reservoir might have been anticipated from the description of the characters of its watershed. Thus it was shown that peat was abundant superficially and in depth, that the drainage from the surface soil was not altogether satisfactory, and that there were places on the gathering ground where the rain saturated and lay stagnant in peaty soil. It is to be noted that Swineshaw Brook, the main inlet stream to the reservoir, was neutral on September 12th, and acid on November 1st, 1894. On the former occasion the brook contained chiefly spring water and very little surface water, and on the latter date, owing to the preceding rains, it was supplying the waterworks with a large quantity of surface peaty water, and proportionately less spring water. The peat drains from Boar Flat probably always yield an acid water, and the same may be said of the small peat drain on the opposite side of the reservoir. Wicken Brook, although found to be neutral on each occasion on which it was tested, may possibly yield an acid water under exceptional circumstances, *e.g.*, during a heavy flood following on a period of drought. The Wicken Springs doubtless always yield a neutral water, but this water apparently is not usually permitted to enter Higher Swineshaw, and is carried instead down the bye-wash, and can be passed into Lower Swineshaw, or into the main stream to Brushes. It is apparent from Experiment 25 of the accompanying table that this spring water is not only neutral, but possessed of considerable acid neutralising ability, and that if turned habitually into Higher Swineshaw, it would materially reduce the acidity of the water in that reservoir. The acidity of Lower Swineshaw is to be traced to the acid water which it receives from the Higher Reservoir. Possibly also the three streams, which enter the reservoir on the east side, may sometimes yield an acid water, although on the occasions on which they were tested they were found to be neutral. On corresponding dates, Higher Swineshaw was more acid than Lower Swineshaw, and the explanation seems to be that the Lower Reservoir receives a neutral water from the Wicken Springs. The neutral condition of Brushes Reservoir is of considerable interest. It is to be noted that the characters of its watershed are very different from those at Higher Swineshaw, *e.g.*, there is less peat, better drainage from the soil, and more spring water, &c., &c. Other points to be noted in this connexion are as follows:—The bed of Brushes is not nearly so peaty as in the case of Higher Swineshaw Reservoir. There is a very considerable amount of leakage from Lower Swineshaw, and the water from this source, after filtering through the rocks, finds its way into the main stream leading to Brushes. This probably accounts for the neutral condition of Brushes main stream, observed on September 12th, 1894. It is true that on November 1st, 1894, this water was acid, but on that date a large amount of acid water from the upper parts of the collecting ground was reaching the stream by way of the bye-wash It is to be noted also that it is possible to supply Brushes with the neutral water from the Wicken Springs. This would of itself be sufficient to account for the reaction of Brushes. Some little difficulty was experienced in getting precise information on this head. Thus, when the gathering ground was visited on September 12th, 1894, the impression was received that the water from the Wicken Springs was occasionally admitted to Brushes. On the second visit, hovever, the waterworks authorities corrected this impression, and explained that the spring water was passed into Lower Swineshaw.

## ASHTON-UNDER-LYNE, STALYBRIDGE, AND DUKINFIELD WATERWORKS.

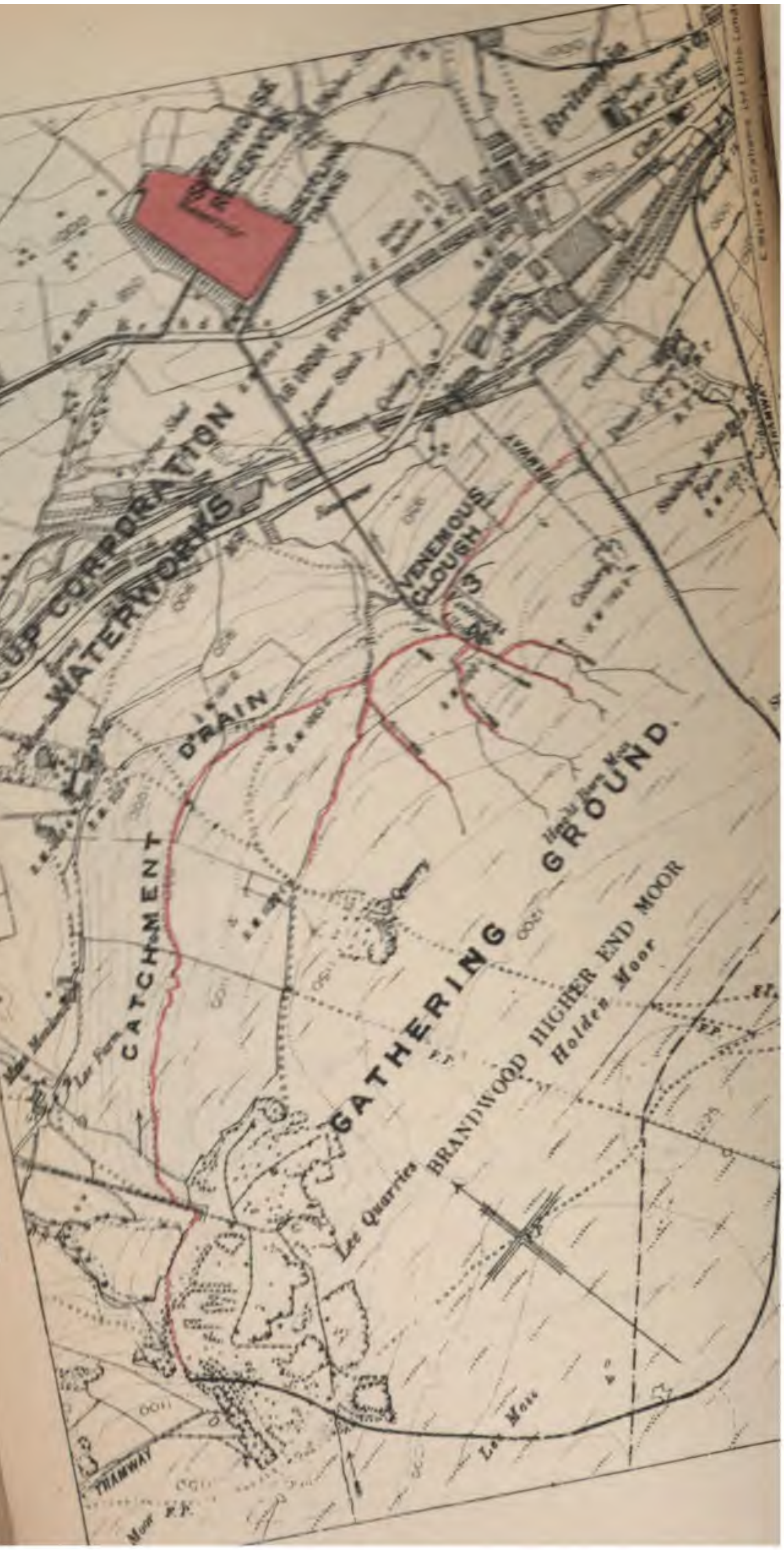
### TABLE 1.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ Parts per 100,000). | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | Feb. 20th, 1894. Yeoman Hey Reservoir at "outlet." | Neutral | Neutral | — | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | Sept. 14th, 1894. Yeoman Hey Reservoir. The sample of water was collected at the side of the reservoir. | Acid | 0·42 | 3·1 | 0·1 | 0·2 | 0·5 | 0·6 | 0·7 | 0·42 |
| | Oct. 20th, 1894. Yeoman Hey Reservoir at "cutlet." | Neutral | Neutral | 3·1 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 9·00 |
| | Sept. 14th, 1894. Brushes Reservoir near "outlet." | Neutral | Neutral | 3·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 5 | Oct. 20th, 1894. Brushes Reservoir near "outlet." | Neutral | Neutral | 3·1 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 6 | Jan. 31st, 1895. Brushes Reservoir near "outlet." | Neutral | Neutral | 3·9 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | Sept. 26th, 1895. Brushes Reservoir near "outlet." | Neutral | Neutral | 3·8 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | Sept. 14th, 1894. Lower Swineshaw Reservoir at "outlet." | Acid | 0·42 | 2·8 | 0·1 | 0·5 | 0·7 | 1·0 | 1·0 | 0·66 |
| | Oct. 20th, 1894. Lower Swineshaw Reservoir at "outlet." | Acid | 0·36 | 2·8 | 0·0 | 0·1 | 0·6 | 0·8 | 0·8 | 0·46 |
| | Sept. 26th, 1895. Lower Swineshaw Reservoir at "outlet." | Faint trace acid. | Trace acid | 4·9 | | | Traces. | | | |
| | Sept. 14th, 1894. Higher Swineshaw Reservoir at "outlet." | Acid | 0·60 | 2·9 | 0·4 | 1·0 | 1·2 | 1·2 | 1·2 | 1·00 |
| | Oct. 20th, 1894. Higher Swineshaw Reservoir at "outlet." | Acid | 0·48 | 3·1 | 0·1 | 0·4 | 0·8 | 0·9 | 1·0 | 0·64 |
| | Jan. 31st, 1895. Higher Swineshaw Reservoir at "outlet." | Acid | 0·48 | 3·4 | 0·2 | 1·0 | 1·2 | 1·2 | 1·2 | 0·96 |
| | Sept. 26th, 1894. Higher Swineshaw Reservoir at "outlet." | Acid | 0·60 | 4·2 | 0·2 | 0·4 | 0·8 | 0·8 | 1·0 | 0·64 |
| 5 | Sept. 14th. 1894. Spring No. 1 to Brushes Reservoir. | Neutral | Neutral | — | — | — | — | — | — | — |

| Experiment. | Description of the Sample of Water. | Reaction with Litmus. | Acidity in Terms of c.c. $\frac{N}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness (CaCO₃ parts per 100,000). | Action on Lead (Results stated as p per 100,000). The action on Lead wa by upward filtration through 50 c washed Lead Shot at the rate of 3 r per 50 c.c. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. |
| 16 | Sept. 18th, 1894. Spring No. 2 in Brushes Reservoir. | Neutral | Neutral | — | — | — | — | — | — |
| 17 | Sept. 18th, 1894. Spring No. 3 in Brushes Reservoir. | Neutral | Neutral | — | — | — | — | — | — |
| 18 | Oct. 29th, 1894. Wicken Brook in Higher Swineshaw Reservoir. | Neutral | Neutral | 5·3 | — | — | — | — | — |
| 19 | Oct. 30th, 1894. Wicken Spring No. 1. | Neutral | Neutral | 4·9 | — | — | — | — | — |
| 20 | Oct. 30th, 1894. Wicken Spring No. 2. | Neutral | Neutral | 5·9 | — | — | — | — | — |
| 21 | Oct. 30th, 1894. Wicken Spring No. 3. | Neutral | Neutral | 5·7 | — | — | — | — | — |
| 22 | Oct. 30th, 1894. Wicken Spring No. 4. | Neutral | Neutral | 5·7 | — | — | — | — | — |
| 23 | Oct. 30th, 1894. Wicken Spring No. 5. | Neutral | Neutral | 5·3 | — | — | — | — | — |
| 24 | Oct. 30th, 1894. Equal parts of the Wicken Spring water (Nos. 1, 2, 3, 4, and 5) mixed together and tested for action on lead. | Neutral | Neutral | — | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 25 | Oct. 30th, 1894. 250 c.c. of the mixed spring water (Experiment 24) mixed with 250 c.c. Higher Swineshaw water (Experiment 12) and tested for acidity and action on lead. | Neutral | Neutral | — | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 26 | Sept. 28th, 1896. Higher Swineshaw Reservoir water after treatment with lime and before entering Lower Swineshaw Reservoir. | ? ft. trace acid. | ? ft. trace acid. | 6·3 | | | | ? Traces. | |

BACUP CORPORATION

(March 30th 1886)



## Survey No. 2.

### BACUP CORPORATION WATERWORKS.

SOURCES OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS (purchased by the CORPORATION OF BACUP from the ROSSENDALE WATERWORKS COMPANY in the Year 1894).

The present supply is obtained from 285 statute acres of moorland gathering ground, situate on the southerly side of and within the borough, embracing the localities known under the names of Holden, Brandwood, and Higher End Moors, Height Barn Moss, and Lee Moss.

The water from the gathering grounds drains naturally into three moorland streams, the central one of which is known as "Venemous Clough,"* and into which the waters from the three streams are collected by means of a covered stone catchwater drain, and stored in a small reservoir formed by the construction of an earth embankment across a narrow gorge.

From this small reservoir (in Venemous Clough) the water is conveyed by means of an 18-inch iron pipe across an intervening valley to settling tanks situate at the inlet of the Sheephouse Storage Reservoir, which has been constructed to intercept peat, sand, and other matters in suspension before the water enters the Sheephouse Reservoir.

From this Sheephouse Reservoir the water at present is conveyed to and distributed for use in Bacup without filtration or other treatment, but extensive works are now in course of construction at the foot of Sheephouse Reservoir embankment for efficient filtration, decolourisation, and purification of the water through sand filters, polarite, and charcoal, and also to counteract the solvent action of the water on lead by an admixture of calcium carbonate or such other chemical as shall be found necessary to remove the solvent action of the water on metallic lead. When these works are completed it is expected that the water supply of the district will be perfectly satisfactory.

No special provision has been made for the exclusion of storm water other than its passage into a compensation reservoir for the statutory supply to the mills on the stream.

The particulars as to gathering ground, rainfall, capacity of reservoir, consumption, &c., are as follows:—

*Gathering Ground.*—285 statute acres.

***Average Rainfall** (estimated)*—

| | |
|---|---|
| Catchment area - - - | 44 inches per annum. |
| Bacup borough - - - - | 44 " " |

---

* For convenience of description these three moorland streams will be referred to Venemous Clough No. 1, No. 2 (the central one), and No. 3.

There is no rain gauge upon the gathering ground. The amount of rainfall here stated is based upon the rain-gauge records of the adjoining catchment belonging to the Heywood Corporation, extending over 50 years. *Daily* records cannot be supplied.

*Sheephouse Storage Reservoir:—*

| | |
|---|---|
| Total capacity - - - | 29,000,000 gallons. |
| Top water, above sea level - | 1,004 feet. |
| Depth - - - - | 27 „ |
| Surface area when full - - | 6 statute acres. |

*Consumption of Water.*—Estimated at 200,000 gallons per day.

### *Characters of the Gathering Ground.*

The gathering ground is entirely composed of moorland. The vegetation consists of coarse pasture grass, heather, and moss.

The surface soil is very peaty, indeed, nearly the whole of the gathering ground is covered with a thick layer of black peat. Underneath the peat is sandstone, shale, and flagstone.

Although the slopes on the moors are sufficient to drain the land, the peat is so abundant superficially and in depth that an enormous quantity of water must be held in its interstices, and a considerable portion of this water during flood time is washed into the supply, fouling it to a serious extent. The amount of spring water or of water altered in character by its passage over or through rock is not great. There are places on the gathering ground where the rain not only saturates the soil but lies stagnating in peaty and mossy pools and in marshy places. Briefly the characters of this gathering ground are such that a very great quantity of peaty water must enter the waterworks especially in flood time, when the Sheephouse Reservoir is being refilled after a drought. The Corporation are, however directing their best attention to improving the present supply (as previously stated) and also to the provision of a new scheme of supply for the district.

### *Conditions found to exist on the Gathering Ground on March* 30, 1896.

Owing to rain the streams were running fuller than normal, and the water both in the streams and in the reservoirs was much discoloured with peaty matter. Lacmoid was used to test the reaction of the various waters. Sheephouse Reservoir was tested at various points, and the water was found to be distinctly acid. The "inlet" water to the reservoir from the settling tanks was also acid. The mountain streams which drain a large area of moorland and which are known as Venemous Clough No. 1, No. 2, and No. 3 were tested at various points, and were found to be acid in each instance. Of these three streams Venemous Clough No. 3 appeared to be the least discoloured with peaty water.

Samples of water were collected for more detailed examination from Venemous Clough No. 1 and No. 2, from the inlet to Sheephouse Reservoir, and from Sheephouse Reservoir, the results are given in an accompanying table. Briefly stated the results of the examination of these waters showed the following. All of the waters were distinctly acid and dissolved lead to a considerable extent. Venemous Clough No. 1 and No. 2 were most conspicuous in this respect, especially the latter, but the inlet water to the reservoir which represented a mixture of water from Venemous Clough No. 1, No. 2, and No. 3 was less acid and acted less strongly on lead than the water of Sheephouse Reservoir. The acidity and plumbo-solvent ability of this water was practically removed by neutralisation with lime water, as is shown in Experiment 5 of the accompanying table.

As regards the bacteriological results, it is to be noted that Sheephouse Reservoir contained a much larger number of micro-organisms than the "inlet" water to the reservoir. Possibly the explanation lies in the fact that a very large amount of peat is worked into the reservoir, and this may produce fermentative changes in the bed of the reservoir associated with the rapid growth and multiplication of bacteria.

Later samples were obtained at intervals more or less periodic from the "inlet" to and the "outlet" from Sheephouse Reservoir. The results of their examination is given in a separate table and will be discussed elsewhere.

## *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the Observed Characters of the Gathering Ground.*

The marked acidity and plumbo-solvent ability which the various waters were found to possess might have been anticipated from the description of the characters of the gathering ground as regards the presence of great quantities of peat and the opportunity afforded the rain of stagnating in the soil. It has been repeatedly noted that water (neutral and free from action on lead) after filtering through peat is usually acid and possessed of plumbo-solvent ability. This has been observed both in the case of water draining from peat on moorland and also in the case of distilled water and rain water filtered through samples of peat in the laboratory.

As regards the great acidity of Venemous Clough No. 1 and No. 2 as compared with "inlet" water to Sheephouse Reservoir, the following points deserve notice. Probably Venemous Clough No. 3 contained on March 30 less acid peaty water than No. 1 and No. 2, and it may be—although this point was not specially noted—that its volume of water was greater. It is not unlikely that the mixing of these waters together, and the subsequent passage of the mixed water for a considerable distance through iron piping and through settling tanks might reduce the acidity. The greater acidity and plumbo-solvent ability of the reservoir water, as compared with the "inlet" water, points to the conditions as regards reaction and action on lead being sometimes reversed. It may be that during heavy floods the inlet water is very much more acid than the water in the reservoir. Experiments show that an acid water under conditions of storage tends to decrease in acidity, but in the case of this water-supply it must be remembered that, notwithstanding the provision of settling tanks, a large amount of peat is washed into the bed of the reservoir, where it may produce fermentative changes associated with an increase of acidity.

There can be no doubt that the provision of a watercourse for the purpose of excluding storm water would beneficially affect the water in Sheephouse Reservoir as regards acidity and plumbo-solvent ability.

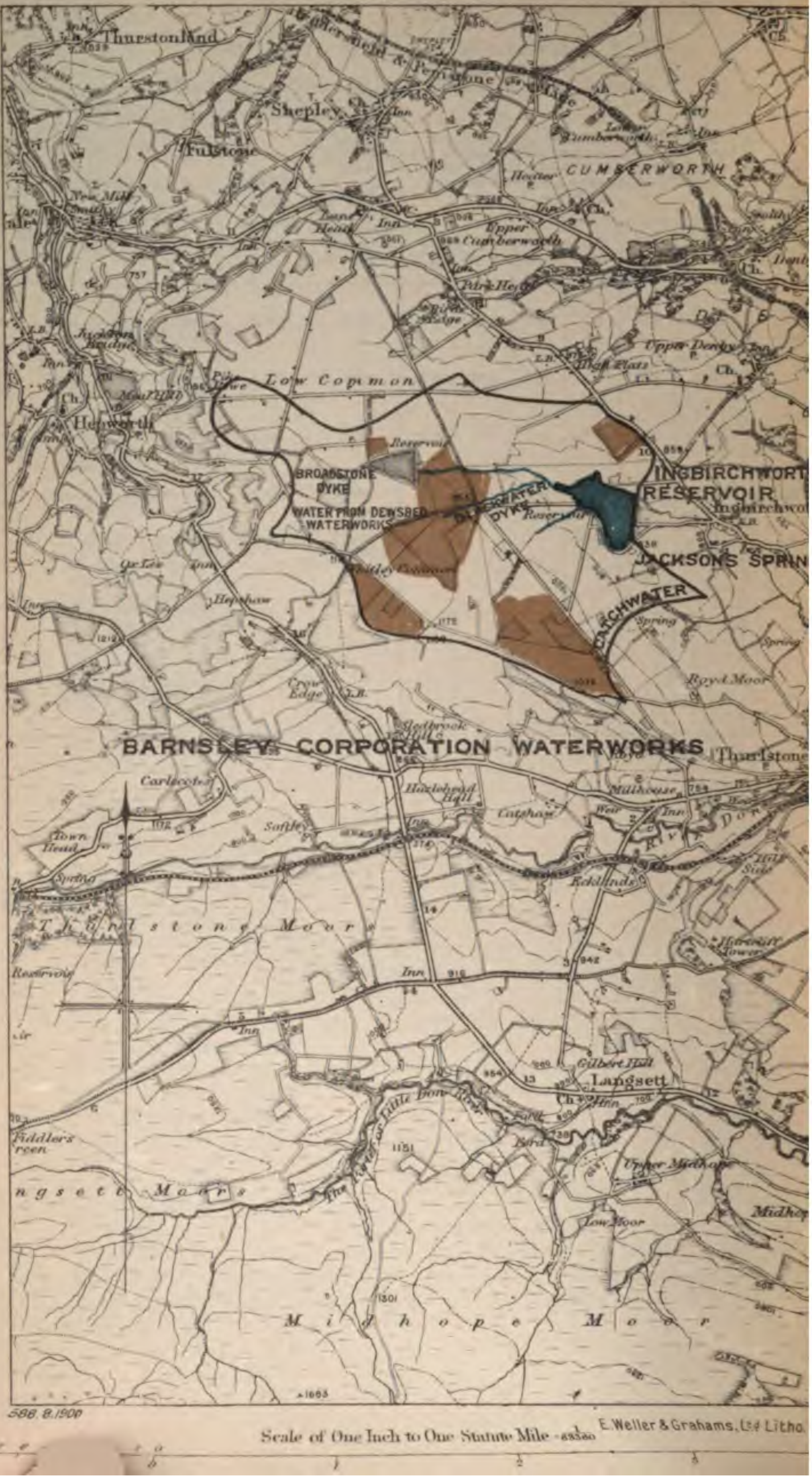
## BACUP (ROSSENDALE) WATERWORKS.

### TABLE 2.—*Chemical and Bacteriological Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | | Numb Mic Organi in 1 c. the W |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. | |
| 1 | Venemous Clough No. 1, March 31st, 1896. | Acid | 0·78 | 0·6 | 1·2 | 1·6 | 1·6 | 1·6 | 1·32 | — |
| 2 | Venemous Clough No. 2, March 31st, 1896. | Acid | 1·08 | 1·5 | 2·0 | 2·5 | 2·5 | 2·5 | 2·20 | — |
| 3 | "Inlet," Sheephouse Reservoir, March 31st, 1896. | Acid | 0·48 | 0·2 | 0·4 | 0·6 | 0·8 | 0·8 | 0·56 | 343 |
| 4 | Sheephouse Reservoir, March 31st, 1896. | Acid | 0·66 | 0·8 | 1·2 | 1·2 | 1·6 | 1·6 | 1·28 | 2825 |
| 5 | A portion of the "inlet" water to Sheephouse Reservoir (experiment 3) was neutralised with lime water and kept in unstoppered bottle for two days, and then tested for acidity and plumbo-solvent ability. | Neutral | ? faint trace acid. | ? traces. | | | | | | — |

# BARNSLEY CORPORATION WATERWORKS

(*July 11th 1895*)



Scale of One Inch to One Statute Mile - 63360 E. Weller & Grahams, Ltd Litho.

## Survey No. 3.

### BARNSLEY CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The water supply of the Barnsley Corporation is derived from moorland gathering grounds situate at Ingbirchworth, near Penistone, about 9 miles west of Barnsley.

There is only one storage reservoir—*Ingbirchworth*—on the gathering ground, and it receives its water supply from the following sources :—

At the south end of the embankment, there is a *catchwater conduit* which extends for a considerable distance in an easterly direction, terminating in a small reservoir, called the Annet Royd Reservoir, and drains a large area of moorland.

Starting from this point and going round the reservoir in a south-westerly direction, the following additional sources of supply are to be noted :—

*Jackson's Spring.*—The water from certain hillside springs is led into a chamber, and from thence is piped into the reservoir at a point not far removed from the catchwater conduit already alluded to.

*Spicer House Brook.*—This is a small stream which contains a variable mixture of spring and surface water.

*Blackwater.*—This stream, which in stormtime contains a considerable quantity of surface peaty water, discharges into the water from Broadstone Dyke, and the mixed water enters the reservoir at its upper end.

*Broadstone Dyke.*—This is a mountain stream, which drains a large area of moorland, and which receives a certain quantity of water from *Dunford Reservoirs* of the Dewsbury and Heckmondwike Waterworks. It unites with Blackwater, and so before discharging into the reservoir represents a variable mixture of Broadstone Dyke water, Dunford Reservoir water, and Blackwater.

The above are the only feeders of any importance supplying Ingbirchworth Reservoir.

The water, after leaving Ingbirchworth Reservoir, is filtered through filter beds, some of which contain Trent sand and pebbles, and others Trent sand, broken gritstone, gritstone ground sand, and mountain limestone. After filtration the water is carried by cast-iron pipes a distance of about 9 miles to the town of Barnsley, the pressure being broken on the way by two covered tanks, one at Hoylandswaine and one at Champany Hill.

By agreement with the Dewsbury and Heckmondwike Waterworks Board, the Corporation of Barnsley purchase from the Board a minimum quantity of 20,000,000 gallons or a maximum quantity of 40,000,000 gallons per annum, which they may commence to take on July 1st in each year, and continue to take at the rate of 200,000 gallons per day for a minimum of 100 days or a maximum of 200 days consecutively. The maximum quantity has been taken only once, viz., in 1893.

The following notes on Barnsley Corporation Waterworks are of interest :—

### *Rainfall.*

Average yearly rainfall in Barnsley, 25·12 inches (average for the last 15 years).

Average yearly rainfall on the gathering ground, 38·15 inches (average for the last 15 years).

### *Capacity, &c., of Ingbirchworth Reservoir.*

| Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|
| 302,000,000 gallons - | 848 feet above Ordnance datum. | 59 feet - | 54 acres. |

### *Consumption of Water.*

At the present 1,150,000 gallons for trade and domestic purposes per day.

At the present 810,000 gallons for compensation water per day for 311 days in the year.

### *Drainage Area.*

1,857 acres, and 53 acres of Broadstone Reservoir; total, 1,910 acres.

### *Daily Rainfall on Gathering Ground from June 11th, 1895 to July 11th, 1895, inclusive.*

| 1895. | Rainfall. | 1895. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| June 11th - - - | 0·08 | June 27th - - - | 0·38 |
| „ 12th - - - | — | „ 28th - - - | 0·25 |
| „ 13th - - - | — | „ 29th - - - | 0·35 |
| „ 14th - - - | — | „ 30th - - - | 0·27 |
| „ 15th - - - | — | July 1st - - - | 0·10 |
| „ 16th - - - | — | „ 2nd - - - | 0·19 |
| „ 17th - - - | — | „ 3rd - - - | 0·34 |
| „ 18th - - - | — | „ 4th - - - | 0·10 |
| „ 19th - - - | — | „ 5th - - - | — |
| „ 20th - - - | — | „ 6th - - - | — |
| „ 21st - - - | — | „ 7th - - - | — |
| „ 22nd - - - | — | „ 8th - - - | — |
| „ 23rd - - - | — | „ 9th - - - | — |
| „ 24th - - - | — | „ 10th - - - | — |
| „ 25th - - - | — | „ 11th - - - | 0·21 |
| „ 26th - - - | 1·25 | | |

## *Notes on the Characters of the Gathering Ground.*

The total area of the watershed is 1,910 acres; of this there are about 12 acres to each of the 160 persons living on the gathering ground; which comprises 227 acres of arable land, 445 acres of meadow land, 622 acres of pasture land, 373 acres of moorland, and 243 acres of roads, streams, reservoirs, quarries, and waste places.

It is especially to be noted that out of the total of 1,910 acres, only 373 are composed of moorland. This gathering ground, then, which is usually considered as a moorland one, is obviously different from the generality of so-called moorland collecting grounds. Briefly its characters may be described as follows:—

Peat is abundant superficially and in depth on the 373 acres of moorland. Elsewhere its distribution is sparse, the surface soil over the rest of the watershed being only slightly peaty in character.

The surface soil over most of the gathering ground rests on gravel and gritstone rock.

Apart from the arable and meadow land, the vegetation consists chiefly of coarse pasture grass. Heather and moss are abundant on the moorland portion of the collecting ground.

The hill slopes are steep, thus allowing the water to run rapidly into the waterworks supply. Towards the source of Blackwater and Broadstone Dyke, however, the conditions are not so favourable in this important respect.

The proportion of spring water to surface water is greater than is usually found in the case of moorland water supplies, and the amount of surface water which is unquestionably peaty in character is far below the average.

There are but few areas, such as exist on most moorland collecting grounds, where the rain saturates the soil and stagnates forming pools and marshy places. The only portions of the watershed where this might possibly take place are on the drainage areas of Blackwater and Broadstone Edge.

Of the water draining into the reservoir, the most peaty water is from Broadstone Edge and Blackwater, particularly the latter.

In conclusion, it is to be noted that this so-called moorland gathering ground is peculiar in the comparative absence of peat, and, in consequence, of peaty water.

## *Conditions found to exist on the Gathering Ground on July* 11th, 1895.

The rainfall from June 11th to July 11th is given in an accompanying table. It is to be noted that for some days previous to July 11th no rain fell on the gathering ground, and the streams feeding the storage reservoir were in consequence very low.

Lacmoid was used to test the reaction of the various waters, and it is to be noted that when a water gives a neutral reaction with this indicator, it will not dissolve lead to any appreciable extent under laboratory conditions of experiment.

The water in Ingbirchworth Reservoir was tested at various points, and was found to be neutral in reaction.

The water in the catchwater, in Jackson's Spring, Spicer House Brook, and in Blackwater Dyke was neutral.

Broadstone Dyke was traced for some distance towards its source, and was found to be neutral in reaction.

The water from the Dunford Reservoirs—Dewsbury and Heckmondwike Waterworks—which mixes with the Broadstone Dyke supply, was found to be distinctly acid, although its acidity was not sufficient to alter the neutral reaction of Broadstone Dyke.

The water from Ingbirchworth Reservoir was tested both before and after passing through the filtration tanks, and it was found to be neutral in reaction.

Samples of water were collected, and subsequently tested for acidity and plumbo-solvent ability, from Ingbirchworth Reservoir, and from the filter beds containing Trent sand and pebbles, and also after passing through the filter beds containing Trent sand, broken gritstone, gritstone ground sand, and mountain limestone. In each case the water was found to be neutral and free from plumbo-solvent ability. The results are given in an accompanying table. It is to be noted that the "hardness" of Ingbirchworth Reservoir water is more marked than is usually found to be the case in moorland waters, and that the "hardness" of the water was greater after filtration through the filter beds containing limestone than after filtration through those which contained no limestone.

## *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

It is to be noted that the conditions found to exist on July 11th were not normal as regards the rainfall. For some days previously no rain had fallen, and in consequence the streams supplying Ingbirchworth Reservoir contained chiefly spring water, and very little surface water. The importance of this observation lies in the fact that the reaction of moorland streams frequently varies according to the rainfall, being usually neutral in time of drought, and often acid in storm time.

The neutral condition of Ingbirchworth would seem to imply that the sum of the waters supplying the reservoir is usually neutral, or at all events that it was so for some time previous to the date of visit. It is quite possible, however, that in storm time the water in Broadstone Dyke and Blackwater Dyke, and in the catchwater may be acid in reaction. Particularly is this likely to be the case with the water from Blackwater Dyke, because this stream drains a considerable area of peaty land.

It is of importance to note that the only acid water was from the Dunford reservoirs, and it may here be noted that the watershed of the Dewsbury and Heckmondwike Waterworks contains much more peat than the one now under discussion. The chemical results appear to be in accordance with the observed characters of the gathering ground. Thus the amount of peat on the Barnsley watershed is very small as compared with most moorland collecting grounds, and the amount of peaty water gaining access to the waterworks is not great in relation to the total yield of water from the drainage area. On the other hand, the amount of spring water and water not essentially peaty in character, is relatively great.

In correspondence with these favourable conditions, it was found that the water in the storage reservoir, and in the streams supplying the waterworks, was neutral in reaction.

The exception was found in the case of the Dunford supply, which was acid, and which came from a source unquestionably peaty.

## BARNSLEY CORPORATION WATERWORKS.

### TABLE 3.—*Chemical Results.*

| scription of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c c. of the Water. | Hardness ($CaCO_3$ parts per 100,000). | Action on Lead (Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 12th, 1895. Ingbirchworth servoir water, near "out-" | Neutral | Neutral | 7·7 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 12th, 1895. Ingbirchworth servoir water after filtration rough Trent sand, broken itstone, gritstone ground nd, and mountain limestone. | Neutral | Neutral | 9·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 12th, 1895. Ingbirchworth eservoir water after filtration rough Trent sand and ebbles. | Neutral | Neutral | 7·8 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |

## Survey No. 4.

### BARROW-IN-FURNESS CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland gathering ground at Pennington and Poaka Beck, both about 10 miles from Barrow.

*Pennington System.*—Pennington Reservoir is supplied with water from a mountain stream—Rathmoss Beck—which drains a large area of moorland. This is the chief source of supply. Another and smaller stream enters the upper end of the reservoir and it drains land similar in character. The water from this reservoir is brought by way of an underground tunnel to Poaka Beck Reservoir. Storm water may be kept out of the reservoir by turning it down a bye-wash. There is, however, no automatic arrangement for excluding such water.

*Poaka Beck System.*—Poaka Beck Reservoir is supplied with water from Poaka Beck and from Pennington Reservoir. Poaka Beck drains a large area of moorland. A small spring discharges its water into the upper end of the reservoir. There is no automatic arrangement for excluding storm water but it may be kept out of the reservoir by turning it down a bye-wash.

The water from Poaka Beck Reservoir is filtered through sand, gravel, and broken slate rock. After filtration the water is carried to the service reservoirs for distribution in the borough.

*Ireleth System.*—The area drainage into Ireleth Reservoir is only about 150 acres. The bulk of the water drains land which is not peaty in character. This portion of the gathering ground was not visited.

The Corporation own nearly all the land bordering the reservoirs, and the streams supplying the reservoirs. The watershed is free from all sources of pollution.

The following notes on Barrow-in-Furness Corporation Waterworks are of interest:—

### *Rainfall.*

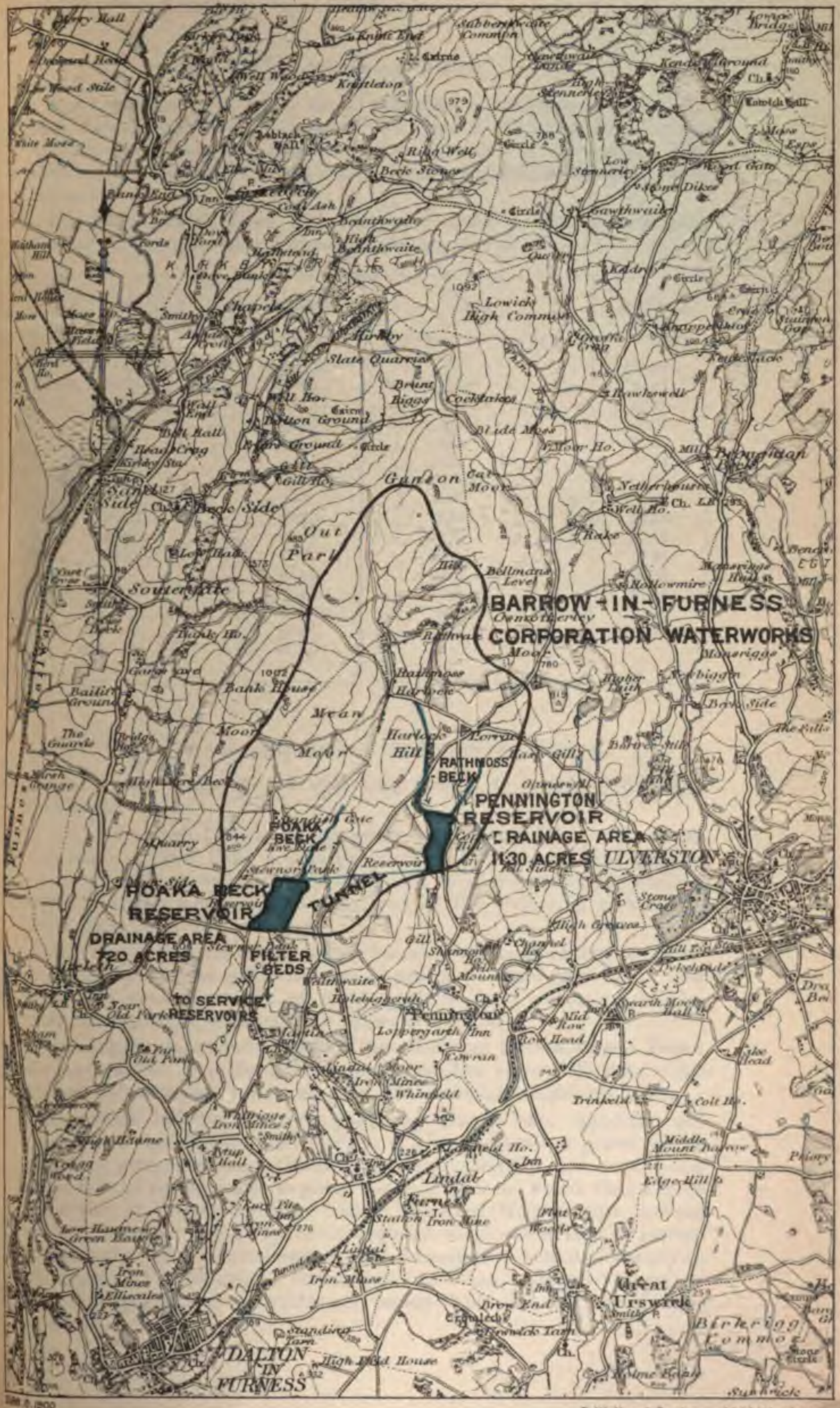
| | Inches. |
|---|---|
| Average yearly rainfall at Barrow-in-Furness - | - 38·00 |
| Average „ „ on gathering ground - | - 52·57 |
| Maximum „ „ „ „ - | - 71·70 |
| Minimum „ „ „ „ - | - 35·17 |

### *Capacity of Reservoirs, &c.*

| Name of Reservoir. | Area of Reservoir. | Top water Line above Ordnance Datum. | Depth of Reservoir. | Capacity of Reservoir. | Drainage Area. |
|---|---|---|---|---|---|
| | Acres. | Feet. | Feet. | Gallons. | Acres. |
| Poaka Beck - | 28·75 | 505 | 44 | 190,300,000 | 720 |
| Pennington - - | 22·5 | 505 | 37 | 138,700,000 | 1,130 |

# BARROW-IN-FURNESS CORPORATION WATERWORKS.

*(March 19th 1896)*



Jan. 6. 1900

E. Weller & Grahams. Ltd. Litho. Lon

Scale of One Inch to One Statute Mile

0 1 2 3

### *Consumption of Water.*

The consumption of water varies according to the state of trade. In 1895 the average daily consumption was about 2,432,000 gallons for the whole district, including 400,000 gallons per day to Ulverston. The total rainfall for that year was 48·47 inches, 610,980,000 gallons were run to waste.

The daily rainfall from 19th February 1896 to 19th March 1896 (date of visit to gathering ground), inclusive, was as follows :—

| 1896. | Rainfall. | 1896. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| February 19th | 0·04 | March 6th | 0·11 |
| " 20th | 0·17 | " 7th | 0·75 |
| " 21st | 0·18 | " 8th | 0·06 |
| " 23rd | — | " 9th | 0·01 |
| " 24th | — | " 10th | 0·44 |
| " 25th | — | " 11th | 0·01 |
| " 26th | — | " 12th | — |
| " 27th | 0·22 | " 13th | 0·50 |
| " 28th | 0·58 | " 14th | 0·16 |
| " 29th | 0·70 | " 15th | 0·44 |
| March 1st | 0·10 | " 16th | 0·02 |
| " 2nd | 0·32 | " 17th | 0·26 |
| " 3rd | 0·13 | " 18th | — |
| " 4th | 0·06 | " 19th | 0·38 |
| " 5th | 0·40 | | |

### *Notes on the Characters of the Gathering Ground.*

Nearly the whole of the gathering ground is composed of waste moorland.

The surface soil is more or less peaty but the amount of peat varies very much. Thus there are large portions of the gathering ground where the soil is only partially peaty and is of comparatively shallow depth. High up on the flatter portions of the gathering ground the soil is most peaty and is deeper.

Speaking in general terms, it may be said that considering the moorland character of the gathering ground peat is far from abundant. The vegetation consists chiefly of rough pasture grass. Heather is also common, especially on the higher slopes of the hills.

Pennington watershed is on the Upper Silurian formation, and Poaka Beck partly on the Upper and partly on the Lower Silurian. The surface soil rests partly on drift, grit, and shale, but mainly on drift.

The water draining from the gathering ground has a rapid fall, and the slope of the hills are precipitous. There are but few places on the gathering ground where the rain stagnates in the soil. As regards the proportion of spring water to peaty water, it is to be noted that a large proportion of the total yield of water is derived from springs or from water which has passed over or through the rock underlying the surface soil, and that only a comparatively small amount is essentially peaty in character. The moorland streams, before being collected for waterworks purposes, run on rocky and sandy beds and for considerable distances.

### *Conditions found to exist on the Gathering Ground on March 19th*, 1896.

The daily rainfall from February 19th to March 19th inclusive, is given above.

The reaction of the various waters was tested with lacmoid—a very delicate test in the case of moorland waters.

*Pennington System.*—Rathmoss Beck was tested at several points along its course and found to be neutral. The water in Pennington Reservoir, was neutral, as was also the water from a small mountain stream entering the reservoir at its upper end.

*Poaka Beck System.*—The water from Poaka Beck, and the water from a spring entering the reservoir at its upper end, and the water in Poaka Beck Reservoir was neutral in reaction.

Samples of water were collected for more detailed examination from Pennington and Poaka Beck Reservoirs. The results are given in an accompanying table. Briefly, the analyses showed that the water from Pennington and Poaka Beck Reservoirs was neutral and free from plumbo-solvent ability. With regard to the water tested on the gathering ground, but not collected for more detailed examination, it is to be noted, that when a water gives a neutral re-action with lacmoid it will not dissolve lead—under laboratory conditions of experiment—to any appreciable extent.

### *Remarks on the Results yielded by the Chemical Examination in reference to the Observed Characters of the Gathering Ground.*

It is to be noted that the water in Pennington and Poaka Beck Reservoirs was neutral; hence it may be concluded that Rathmoss Beck and Poaka Beck supply, under ordinary conditions, their respective reservoirs with neutral water. It appears that an acid water may become partially neutralised under conditions of storage, but when the water in a reservoir is found to be neutral, the presumption, nevertheless, is that its inlet streams supply it with neutral water. When the water in a reservoir is found to be acid, and its inlet streams neutral, experience shows that it is only in time of drought that the "feeders" are neutral, and that in flood time they are markedly acid. But when a reservoir water is neutral and its inlet streams acid, then either the acidity is very slight or dependent on heavy rain following a period of drought. In this case, and under ordinary conditions of rainfall, the acidity is usually not only "nil," but the water has some acid neutralising ability. Mention has already been made of a spring entering Poaka Beck Reservoir. This water was neutral, and it is to be noted that moorland springs are usually not only neutral but possess some acid-neutralising ability. Sometimes, indeed, the water from these springs, as it issues from the ground, is acid when tested with lacmoid. The acidity (probably due to $CO_2$) usually disappears, however, on exposure of the water to air. As explaining the neutral condition of Rathmoss Beck and Poaka Beck, the following points are to be noted. Although the drainage area is moorland, the amount of peat is not very great. There is a large amount of spring water and of water which has become altered in character by its passage over or through the rock underlying the surface soil. The precipitous slope of the hills allow of rapid superficial drainage. There are but few places where the rain stagnates in beds of peat or moss. The streams run for the most part along rocky and sandy beds, and for a considerable distance. It is only towards their source that they drain land unquestionably peaty. Lower down they are bordered by plantations of trees and pasture land.

## Barrow-in-Furness Corporation Waterworks.

### Table 4.—*Chemical and Bacteriological Results.*

| Experiment. | Description of the Sample of Water. | Acidity. | | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | | Micro-organism in 1 c.c. of the Water. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Reaction with Lacmoid. | In Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. | |
| 1 | Pennington Reservoir water, March 20th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 495 |
| 2 | Poaka Beck Reservoir water, March 20th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 249 |

## Survey No. 5.

## BATLEY CORPORATION WATERWORKS.

### SOURCE ON THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland gathering ground, situated 20 miles S.W. of Batley, on the eastern slope of the Pennine chain, near the Holmfirth terminal of the Lancashire and Yorkshire Railway.

There are three reservoirs on the gathering ground, and two of these —Riding Wood and Ramsden—are used only for compensation purposes. The remaining reservoir (Yateholme), furnishing water for domestic uses in the borough of Batley, is supplied with water from the three following sources:—

(1.) *Spring Water.*—The spring water, although a constant source of supply, is not very abundant. It enters the S.W. side of Yateholme Reservoir.

(2.) *Great Bent Dyke.*—This is a moorland stream which contains a variable mixture of surface water and of spring water. During drought the amount of surface water is very small, and in flood time very great. It enters the reservoir at its southern angle.

(3.) *Ramsden Clough.*—This stream comes from Ramsden Valley, and is tunnelled through a hill and enters the S.E. side of the reservoir. Ramsden Clough, like Great Bent Dike, contains a variable mixture of surface water and spring water.

Netherley Clough, west of Great Bent Dyke, which gravitates into Ramsden Reservoirs only, is a similar stream to the others, but some valuable springs issue into the westerly side of it. Consequently the dry weather flow of this stream is greater than that of the other two.

There is a watercourse which connects Great Bent Dyke with Netherley Clough and Ramsden Compensation Reservoir. During floods the water from Great Bent Dyke is prevented from entering Yateholme Reservoir, and is directed into this watercourse by means of an ingenious floodgate arrangement which works automatically.

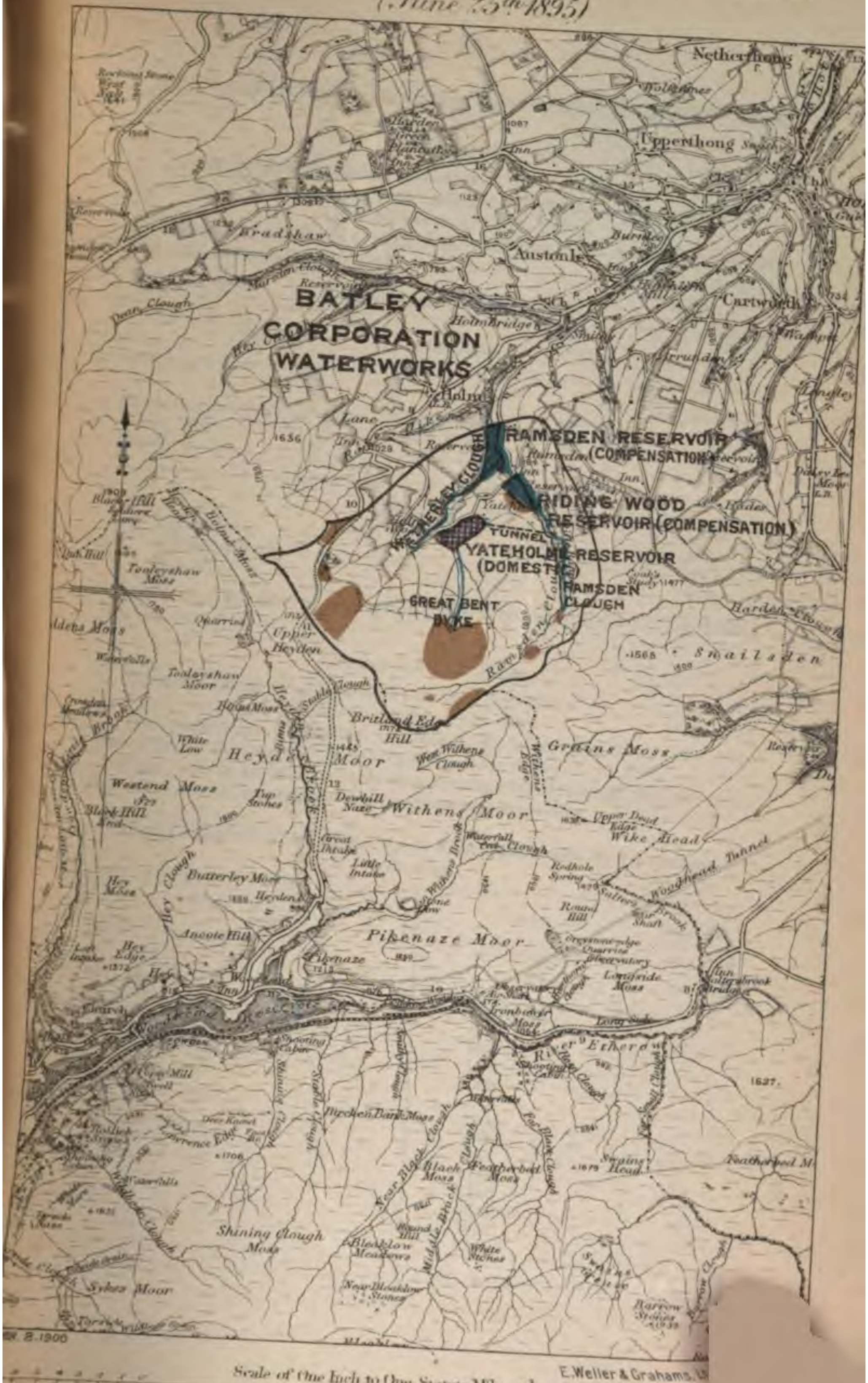
A somewhat similar arrangement exists in connexion with Ramsden Clough. During fair weather the water in Ramsden Clough passes along through a tunnel watercourse into Yateholme Reservoir. In flood time the water is turned down the natural course of the stream to Riding Wood Compensation Reservoir. This is effected by means of an automatically working floodgate arrangement situated in the Ramsden Valley.

All the main streams and subsidiary feeders and springs in the Ramsden Valley *below the level* of Yateholme Reservoir are collected at one point by iron conduits and regulated by penstocks and sluice valves, in order to intercept the fair weather flow which would not otherwise gravitate into Yateholme Reservoir. This water is then taken direct to Batley, instead of allowing it to run into the compensation reservoirs. By this arrangement the water in Yateholme Reservoir can always (if desired) be kept at a high level without any flood water ever being admitted into it.

In conclusion, it is to be noted that Batley is supplied with water from Yateholme Reservoir, and the fair-weather flow from the lower part of Ramsden Clough, and that Yateholme Reservoir is supplied with spring water and the fair-weather flow from Great Bent Dyke and the upper part of Ramsden Clough.

## WATERWORKS.

(June 25th 1895)



Scale of One Inch to One Statute Mile

E.Weller & Grahams, L

The following notes on Batley Corporation Waterworks are of interest:—

### *Rainfall.*

| | Inches. |
|---|---|
| Average yearly rainfall in Batley - - - | 23·87 |
| „ „ „ on gathering ground - - | 58·43 |

(For 10 years, 1885 to 1895).

Rain-gauge in Batley, 492 feet above sea; at gathering ground, 861·333 feet above sea level.

### *Capacity, &c., of Reservoirs.*

| Name. | Capacity. | Depth. | | Area. |
|---|---|---|---|---|
| | Gallons. | Ft. | in. | Acres. |
| Yateholme Reservoir - - | 90,000,000 | 38 | 8 | 16 |
| Riding Wood „ - - | 54,700,000 | 59 | 0 | 10 |
| Ramsden „ - | 86,773,000 | 67 | 9 | 12 |

### *Drainage Area.*

| | Acres. |
|---|---|
| Yateholme - - - - - - | 322 |
| Riding Wood - - - - - - | 583 |
| Ramsden - - - - - - | 692 |

Note that the drainage area to Riding Wood is utilised for Yateholme by the tunnel.

### *Consumption of Water.*

Domestic purposes, 12 gallons per head per diem.

Trade purposes, 27 gallons per head per diem.

The population of Batley is 30,000, therefore the total daily consumption in the borough is 1,170,000 gallons a day.

Note that in addition to this consumption 1,121,400 gallons are each working day delivered into the rivers as compensation.

### *Daily rainfall from 25th May to 25th June 1895, on Gathering Ground.*

| 1895. | Rainfall. | 1895. | Rainfall. |
|---|---|---|---|
| | Inches. | | Inches. |
| May 25th - - - | — | June 11th - - - | — |
| „ 26th - - - | ·1 | „ 12th - - | — |
| „ 27th - - - | — | „ 13th - - - | — |
| „ 28th - - - | — | „ 14th - - - | — |
| „ 29th - - - | — | „ 15th - - - | — |
| „ 30th - - - | ·1 | „ 16th - | — |
| „ 31st - - - | — | „ 17th - - - | — |
| June 1st - - - | — | „ 18th - - | — |
| „ 2nd - - - | ·9 | „ 19th - - - | — |
| „ 3rd - - - | — | „ 20th - - | — |
| „ 4th - - - | — | „ 21st - - - | — |
| „ 5th - - - | — | „ 22nd - - | — |
| „ 6th - - - | — | „ 23rd - - - | — |
| „ 7th - - - | — | „ 24th - - | — |
| „ 8th - - - | — | „ 25th - - - | — |
| „ 9th - - - | — | | |
| „ 10th - - - | — | Total - - | 1·1 |

Note that from the 25th of May to the 25th of June 1895 there was rain on three days only.

### *Notes on the Characters of the Gathering Ground.*

The gathering ground is a moorland one, but it is to be noted that peat is not abundant either superficially or in depth.

Nearly the whole of the gathering ground is covered with pasture grass, and the soil is only slightly peaty in character, and is thin and well drained.

The rock underlying the surface soil is chiefly millstone grit.

The slopes of the hills are such as to allow of very rapid surface drainage, and it appears that there are no areas such as exist on most moorland gathering grounds, where the rain can stagnate in peaty or boggy or marshy places.

There is a considerable amount of spring water besides the water derived from mere surface drainage.

In conclusion, it is to be noted that the characters of the gathering ground are remarkably good as regards the comparative absence of peat and peaty water.

### *Conditions found to exist on the Gathering Ground on June 25th, 1895.*

The daily rainfall previous to June 25th, 1895, is given in an accompanying table. It is to be noted that the rainfall was much below the average, and in consequence the streams on the gathering ground contained chiefly spring water, and very little surface water. The reaction of the various waters was tested with an alcoholic solution of lacmoid.

Ramsden Clough was tested at its entrance into Yateholme Reservoir, and also at several points along its course in Ramsden Valley. The water was neutral, and the water in Great Bent Dyke and the spring water had a similar reaction. Yateholme Reservoir water was tested in several places, and found to be very faintly acid. Netherley Clough, and Riding Wood, and Ramsden waters all contained neutral water.

Samples of water were collected for more detailed examination from Yateholme Reservoir, Ramsden Clough, and the spring water. Later a sample of Batley main water was obtained. The results of the chemical examination of these waters is given in an accompanying table. Briefly, the results showed that Ramsden Clough and the spring water were neutral in reaction, and free from plumbo-solvent ability. Yateholme Reservoir water and Batley main water showed traces of acidity and plumbo-solvent ability. Another sample of Yateholme Reservoir water was obtained on December 20th, 1895, and on examination yielded results similar to the above.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

It is to be noted that Ramsden Clough and Great Bent Dyke were neutral on June 25th, 1895. Possibly during heavy floods, these waters may contain sufficient peaty water to acquire an acid reaction, although the ingenious arrangement by which storm water is automatically diverted from the waterworks would prevent fouling of Yateholme

Reservoir. The very faint acidity of Yateholme Reservoir may possibly be due to Ramsden Clough and Great Bent Dyke containing traces of acid during the beginning and end of storms, when the rush of water would be insufficient to close the flood gates.

It is of interest to note that the condition of the water as regards freedom from acidity and action on lead is quite in accordance with the observed characters of the gathering ground. Thus it has been repeatedly observed in the case of moorland gathering grounds that, on the one hand, when peat is abundant superficially and in depth, and the rain can stagnate in the soil, the quality of the water as regards acidity and plumbo-solvent ability is unsatisfactory, and that, on the other hand, where—as in this particular instance—the peat is comparatively scarce, and the drainage from the soil good, the quality of the water is usually above suspicion.

### BATLEY CORPORATION WATERWORKS.

TABLE 5.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$, Parts per 100,000). | Action on Lead (Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | Yateholme Reservoir, water, June 26th, 1895. | ? Faint trace acid. | ? Faint trace acid. | 3·36 | ? Faint traces. | | | | | |
| 2 | Ramsden Clough water, June 26th, 1895. | Neutral | Neutral | 3·5 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 3 | Spring water to Yateholme Reservoir, June 26th, 1895. | Neutral | Neutral | 6·86 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 4 | Batley main water, June 29th 1895. | ? Faint trace acid. | ? Faint trace acid. | 3·22 | ? Faint traces. | | | | | |
| 5 | Yateholme Reservoir water, December 20th, 1895. | ? Faint trace acid. | ? Faint trace acid. | — | Traces. | | | | | |
| 6 | Ramsden Clough water. Water collected after heavy rains succeeding drought, July 31st, 1895. | Neutral | Neutral | 3·6 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 7 | Great Bent Dyke water. Water collected after heavy rains succeeding drought, July 31st, 1895. | Neutral | Neutral | 3·1 | ? Very faint traces. | | | | | |

Samples of storm water from Ramsden Clough and Great Bent Dyke were obtained on December 30th, 1896, and they were examined for acidity and plumbo-solvent ability. The great turbidity of the water made it impossible to determine accurately the amount of the acidity and action on lead. Both waters were, however, unquestionably acid and possessed of plumbo-solvent ability, and Great Bent Dyke water was considerably the worst of the two.

## Survey No. 6.

## BLACKBURN CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland about 20 miles from Blackburn, in the Brennand and Whitendale Valleys. The water withdrawn for waterworks purposes from the above gathering grounds is received, in each instance, into a screen chamber situated some 775 feet above sea level. The screens contain 576 meshes to the square inch. The water after passing, in each instance, through the screening chamber is carried by a 30-inch cast-iron pipe from the chamber to Footholme. At Footholme, the Brennand and Whitendale waters unite, and are carried in a single 30-inch main (Bowland main) to three service reservoirs. Additional screening arrangements exist in connexion with each service reservoir. The water is delivered to the town without filtration.

More in detail, the arrangements for collecting water are as follows:—

Water from Brennand river is carried in a conduit to Brennand screen chamber, which receives also, by a separate conduit, water from certain small moorland tributary feeders known as Far Pasture, Well Spring, and Folds Clough.

The water from Whitendale river is carried, together with the water from some small subsidiary feeders, into the Whitendale screen chamber. In addition, the 30-inch cast-iron pipe conveying the water from this chamber to the Bowland main receives on its way the water from three small moorland streams, called Stony Clough, Costy Clough, and Little Costy Clough.

At the intake from each tributary stream there is a collecting pond having a rough stone filter at its upper end, through which all the water passes before reaching the conduit.

Storm water is prevented from entering the conduits by means of "leap" weirs. These are mechanical contrivances which permit the dry-weather flow or clear water to drop through an opening leading to the conduit, but which prevents flood water from so entering into the water supply, owing to the great velocity and volume of the storm water carrying it over and beyond the opening leading to the conduit and onwards into the stream to serve as "compensation" water.

There are, at present, no catchment reservoirs on the gathering ground. It is proposed, however, to construct two reservoirs, one in the Brennand Valley, on the course of the Brennand river, another in the Whitendale Valley, on the course of the Whitendale river, at heights of 775 and 675 feet above sea level respectively.

The following notes on Blackburn Corporation Waterworks are of interest:—

*Rainfall.*

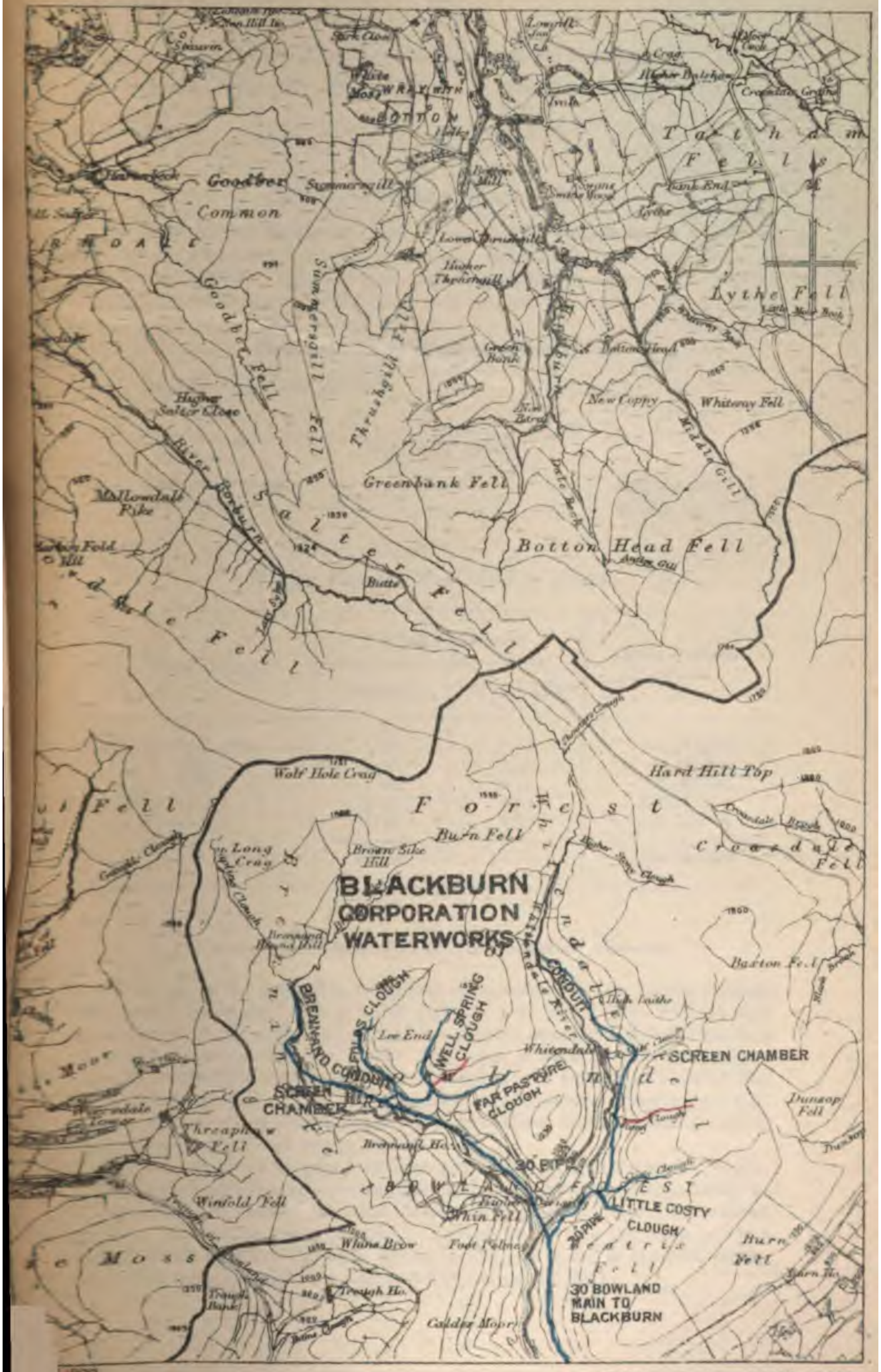
| | |
|---|---|
| Average yearly rainfall in Blackburn - | - 38 inches |
| " " " on gathering ground | - 59 " |

*Capacity of Blackburn Service Reservoirs.*

| | |
|---|---|
| Audley Reservoir - | - 13,000,000 gallons. |
| Fishmoor " - . - | - 310,000,000 " |
| Guide " . . | - 87,000,000 " |

# BLACKBURN CORPORATION WATERWORKS.

*(March 12th 1896)*



E Weller & Graham Ltd Litho London.

*Scale of One Inch to One Statute Mile — 1/63360*

### *Top Water Levels of Blackburn Service Reservoirs.*

| | |
|---|---|
| Audley Reservoir | 592 feet above sea level. |
| Fishmoor " | 600 " " |
| Guide " | 642 " " |

### *Delivery of 30-inch Bowland Main.*

| | |
|---|---|
| Into Audley Reservoir | 6,900,000 gallons per day. |
| " Fishmoor " | 6,400,000 " |
| " Guide " | 4,800,000 " |

### *Consumption of Water in Blackburn.*

3½ million gallons per day.

### *Drainage Area.*

| | |
|---|---|
| Brennand system | 2,300 acres. |
| Whitendale " | 3,050 " |

### *Weekly Rainfall and Yield of Water.*

| Week ending | Rainfall (Inches). | | Yield of Water (Gallons). |
|---|---|---|---|
| | Brennand. | Whitendale. | |
| February 14th, 1896 | 1·90 | 1·44 | 141,754,000 |
| " 21st " | 0·56 | 0·49 | 71,162,000 |
| " 28th " | 1·05 | 0·85 | 79,788,000 |
| March 6th, 1896 | 4·46 | 4·34 | 493,536,000 |
| " 13th " | 3·26 | 3·54 | 350,460,000 |
| Totals | 11·23 | 10·66 | 1,136,700,000 |

### *Notes on the Characters of the Gathering Ground.*

The gathering ground is composed of moorland. The larger portion is grassy moorland, only a small portion peat bog. The surface soil over most of the gathering ground is peaty in character, but except in a few places its depth is not great. Its depth is least on the precipitous slopes of the hills, and greatest on the upper and flatter portions of the gathering ground. The vegetation is chiefly coarse, actively growing, grass, but there is also heather in places where there exists decaying vegetable matter and boggy land.

The more or less peaty surface soil rests on grit or shale, which, immediately underneath the surface soil, is disintegrated and sandy in character. In storm time large quantities of sand and debris are washed down as well as peaty matter. Especially is this the case on the precipitous slopes of the hills, as the fall of the water is greatest there, and the covering soil thin and in many places deficient.

Generally speaking, the slopes of the hills are precipitous and tl covering soil thin, so that the fall of the water is rapid, and there is litt stagnation of water in the soil.

The proportion of spring water to surface drainage water is difficu to judge of on moorland gathering grounds. In this instance, and ordinary conditions of rainfall, a considerable amount of the total yie of water appears to have passed through the soil, and to have becor more or less altered by its passage through or over the underlying roc No doubt in storm time the conditions are altered, and the bulk of t water is obtained from surface drainage. As has been already state however, this water does not pass to the waterworks.

The water in most of the feeders runs on rocky and sandy beds, n on clay bottoms.

The distance the water runs in the streams and in the conduits befo reaching the screening chambers is considerable.

### *Conditions found to exist on the Gathering Ground on March 13th*, 1896.

The conditions found to exist on March 13th, 1896, probably repr sent fairly well the normal, as regards the amount of water in t feeders and the degree of moisture in the soil. The weekly rainfall ai yield of water, from February 14th to March 13th inclusive, are given an accompanying table.

### BLACKBURN CORPORATION WATERWORKS.

### BOWLAND GATHERING GROUND.

### *Weekly Rainfall and Yield of Water.*

| Week ending | Rainfall (inches). | | Yield of Water (Gallons). |
|---|---|---|---|
| | Brennand. | Whitendale. | |
| February 14th, 1896 - - | 1·90 | 1·44 | 141,754,000 |
| „ 21st „ - - | 0·56 | 0·49 | 71,162,000 |
| „ 28th „ - - | 1·05 | 0·85 | 79,788,000 |
| March 6th, 1896 - - - | 4·46 | 4·34 | 493,536,000 |
| „ 13th „ - - | 3·26 | 3·54 | 350,460,000 |

The reaction of the various waters was tested with an alcoho solution of lacmoid, which is a very delicate test for acidity in the ca of moorland waters.

*Brennand System.*—The water in the conduit from the Ri Brennand was neutral in reaction; the water entering the scre chamber from the conduit serving the tributaries was either neutral only very feebly acid. As to the streams themselves, Far Pasture, Clough, Folds Clough, and Brennand river were all neutral, but Well Spring Clough had a faintly acid reaction, while a small peat feeder into Well Spring Clough was distinctly acid. After passing the screen the water was practically neutral, although it was open to question whether it contained traces of acid or not.

*Whitendale System.*—The water in Whitendale river, and in the conduit from the Whitendale river, and the water in the screen chamber, was either neutral or contained only the faintest possible trace of acid. Stony Clough stream was distinctly acid; it appeared to drain a more peaty area, and possibly an area where there was exceptional opportunity for stagnation of the rain in the soil. It was found, however, that the acidity of this feeder was not sufficient to alter the reaction of the body of water from the Whitendale system. Costy Clough and Little Costy Clough streams were neutral in reaction.

It may here be stated, that experiments show that when a water does not give a distinctly acid reaction with lacmoid, it will not dissolve lead, to any appreciable extent, under laboratory conditions of experiment. The water therefore from the Brennand and Whitendale systems, under ordinary circumstances, may be regarded as neutral, and free from plumbo-solvent ability.

Between the Brennand and Whitendale Valleys an area was found where the rain saturated a somewhat deeper peaty soil. The vegetation was bare in places, and here and there heather grew, but for the most part the surface was covered with moss and the long coarse grass which is so frequently found in marshy places. The water lying in several small marshy pools here was tested and found to be acid in reaction.

None of the water from this area reaches the water supply.

Samples of water were obtained for detailed examination from the Brennand and Whitendale screen chambers, a small peat feeder to Well Spring Clough, and Stony Clough. Later, a sample of the water as supplied to Blackburn was also examined. The results of the examination of these waters is shown in an accompanying table. Briefly, the analysis of these waters showed that the sample of Blackburn water was neutral and free from plumbo-solvent ability, and that the water from the Brennand and Whitendale systems was practically neutral and did not dissolve lead to any appreciable extent. The water from Stony Clough and a little peat feeder to Well Spring Clough was distinctly acid, and dissolved lead to a considerable extent.

### *Remarks on the Results yielded by the Chemical Examination in reference to the observed Characters of the Gathering Ground.*

It is to be noted that Blackburn is supplied with a moorland water which—judging from the above experiments—is practically neutral and free from plumbo-solvent ability. Since moorland waters have come to be associated with acidity and plumbo-solvent ability, it is important to know why this water differs from other, and apparently similar, waters in this important respect. In this connexion the following points especially deserve consideration—

The exclusion of storm water by means of "leap" weirs, the provision of "wreck" lodges with stone filters at their upper ends, the screening arrangements, the flow of water for considerable distances along rocky and sandy beds, the precipitous slopes allowing of a rapid flow of water and efficient drainage of the soil, the comparative absence of peaty and boggy land, the shallowness of the peat beds, the active growth of vegetation and the small proportion of peaty water to spring water or water not peaty in character—all these here tend to prevent the water acquiring an acid reaction.

The exclusion of "storm" water is important, because heavy rain washes out of the soil substances (formed since the previous flood) which, when derived from peat, appear to give to moorland waters their acidity and plumbo-solvent ability. The provision of "wreck" lodges having rough stone filters at their upper ends, and of screen chambers, prevent the grosser forms of impurities, *e.g.*, peaty matters, from entering the water supply. The flow of the water for considerable distances along rocky and sandy beds is believed to be beneficial as tending to neutralise any acids contained in the water. It has been observed in the case of moorland waters that when a reservoir leaks, the water, if acid, within the reservoir becomes usually neutralised after its passage through the rock. In this connexion it is noteworthy that in flood time a large amount of disintegrated rock is washed into the feeders. This rock underlies the peat, and in many places breaks through to the surface where the soil covering is deficient. Again, the mere delay of a water on its course appears to be salutary, as experiments show that keeping an acid water for some time exposed to the air tends to diminish slightly its acidity. The precipitous slopes, allowing of a rapid flow of water and efficient drainage of the soil, cannot but be beneficial, because stagnation of the water in the peaty soil is thereby prevented, the decay of vegetation is restrained, and the active growth of grass is encouraged.

The comparative absence on the gathering ground of peaty and boggy land is very important, because experience has shown that the water derived from such areas is apt to be very acid and to dissolve lead. The shallowness of the peat beds limits the mischief done by peat in connexion with the water supply. On some gathering grounds, the peat beds not only cover large areas, but attain a thickness of 10 to 20 feet.

The active growth of vegetation usually indicates that the soil is well drained, and that it is only partially peaty in character. The active growth of grass binds the soil together, and it has been repeatedly noticed that water draining from such areas is usually neutral and free from plumbo-solvent ability, while water draining from adjacent areas not covered with grass, but with heather, or, it may be, destitute of any growing vegetation, is often acid, and dissolves lead to a considerable extent.

The small proportion of peaty water to spring water or to water not peaty in character means that the water derived from peat drainage is small in quantity as compared with the water obtained from spring, or from the drainage of land not essentially peaty, or from the drainage of peat land, which by percolation or otherwise has lost its characters as a peaty water.

Of the samples of water examined for acidity and plumbo-solvency, it is to be noted that only two, viz., Stony Clough and the water from a small peat feeder to Well Spring Clough, showed any appreciable acidity and plumbo-solvent ability. So far as could be ascertained these two waters contained more peaty water than the other feeders. It is possible that in storm time the bulk of peaty water might be increased sufficiently to alter the reaction of many of the feeders which were found to be neutral under ordinary conditions of rainfall, but, as has been already stated, the storm water is excluded from the water supply.

## BLACKBURN CORPORATION WATERWORKS.

### *Table 6.—Chemical and Bacteriological Results.*

| Experiment. | Description of the Sample of Water. | Acidity. | | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by means of upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | | Number of Micro-organisms in 1 c.c. of the Water. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Reaction with Lacmoid. | In terms of cc. $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. | |
| 1 | March 13th, 1896. Water from the Whitendale screen chamber after screening. | ? trace acid. | ? trace acid | ? trace | ? trace | ? trace | ? trace | ? trace | ? trace | — |
| 2 | March 13th, 1896. Water from the Brennand screen chamber after screening. | ? trace acid. | ? trace acid | ? trace | ? trace | ? trace | ? trace | ? trace | ? trace | 360 |
| 3 | March 13th, 1896. Water from small peat feeder to Well Spring Clough. | Acid | 0·54 | 0·1 | 0·2 | 0·3 | 0·3 | 0·3 | 0·24 | |
| 4 | March 13th, 1896. Water from Stony Clough, Whitendale system. | Acid | 0·30 | 0·1 | 0·2 | 0·2 | 0·2 | 0·3 | 0·20 | 270 |
| 5 | June 26th, 1896. Water from Blackburn main. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | — |

## Survey No. 7.

### BOLTON CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland gathering ground at Entwistle, Springs, and High Rid about 7, 4, and 3 miles from Bolton respectively.

*Entwistle System.*—The gathering ground is composed of moorland. Cadshaw Brook is the chief source of supply, and it, together with some smaller mountain streams, enters Entwistle Reservoir. These streams drain a very large area of moorland. No arrangement exists for the exclusion of storm water, but the water after leaving Entwistle Reservoir is filtered through sand and gravel at Sweetloves, from whence it enters the distribution pipes.

*Springs System.*—There are two reservoirs (Springs and Dingle) on this moorland gathering ground. A large mountain stream enters the upper (Springs) of these two reservoirs, and this practically is the only source of supply. The water from Springs Reservoir passses into the lower (Dingle) reservoir. The water from Dingle Reservoir can be filtered but usually it is carrried into consumption without any filtration. There is no arrangement for excluding storm water from this system of water supply. The water is conveyed from the Dingle Reservoir in a 24-inch stone culvert to the Sweetloves Service Reservoir.

*High Rid System.*—This gathering ground can hardly be described as a moorland one, since the chief source of supply is from springs which are piped into a common channel which discharges into High Rid Reservoir. The water is conveyed from the High Rid Reservoir in a 3-foot stone culvert to the filter beds (sand and gravel) at Heaton, from whence it enters the distribution pipes.

The following notes on Bolton Corporation Waterworks are of interest:—

*Rainfall.*

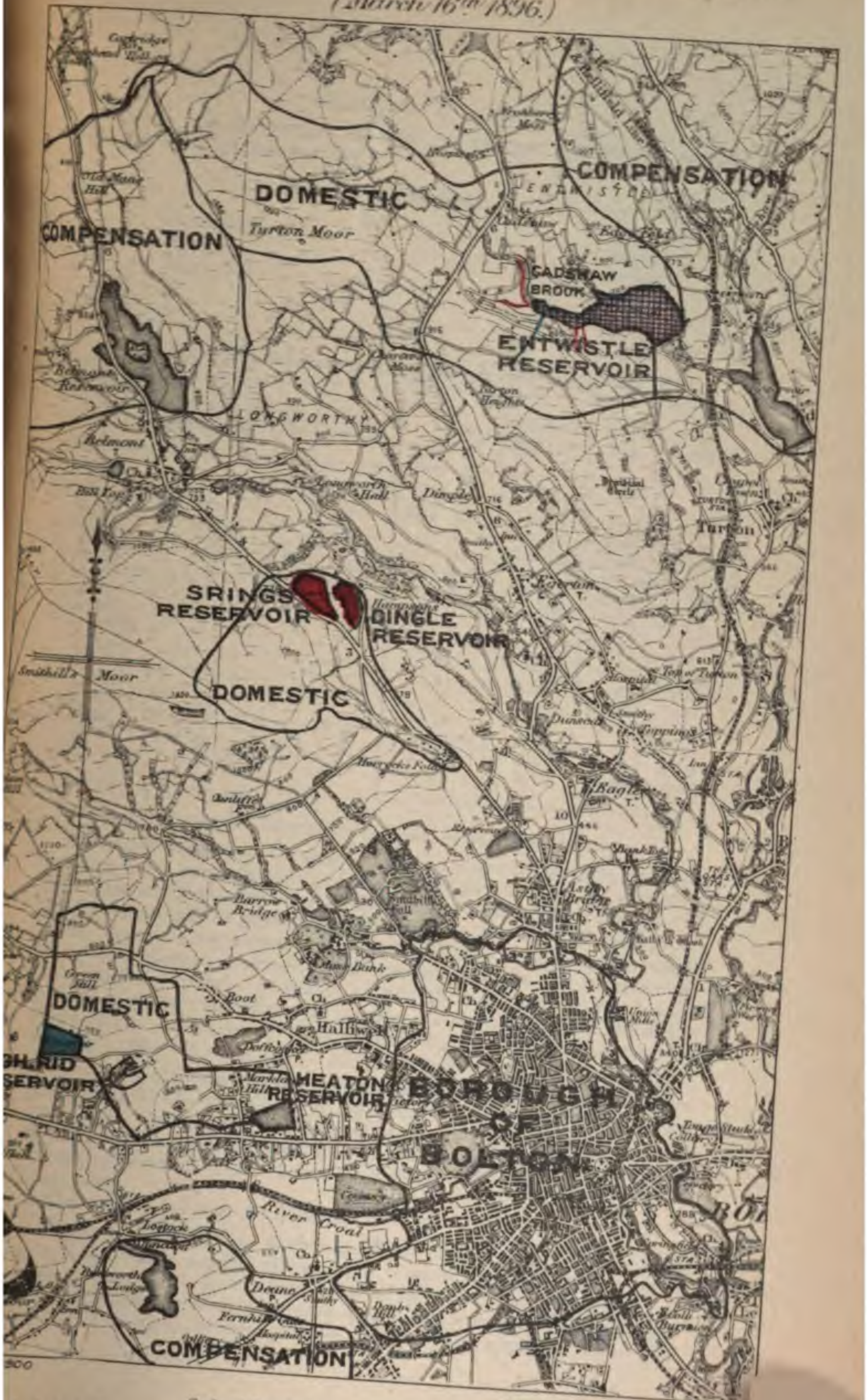
| | Inches. |
|---|---|
| Yearly rainfall in Bolton (average of 9 years) - - | 39·05 |
| „ „ on Entwistle gathering ground (average of 28 years) - - - - - - | 53·10 |
| Yearly rainfall on springs (average of 53 years) - | 56·82 |
| „ „ on High Rid (average of 37 years) - | 42·12 |

*Capacity, &c. of Reservoirs.*

| —— | Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|---|
| | | | Ft. | Acres. |
| Entwistle - - | 625,000,000 | 690·35 above O.D. | 100 | 94 |
| Springs - - | 134,000,000 | 757·56 „ - | 48 | 24⅔ |
| High Rid - - | 130,000,000 | 578·50 „ - | 34 | 25½ |

# BOLTON CORPORATION WATERWORKS.

*(March 16th 1896.)*



Scale of One Inch to One Statute Mile

E. Weller & Grahams, Ltd Litho. Lond

### *Consumption of Water.*

For the first nine months of 1896 the average consumption of water was 5,587,191 gallons per day.

### *Drainage Areas.*

| | Acres. |
|---|---|
| Entwistle - - - - - - | 2,118 |
| Springs - - - - - - | 525 |
| High Rid - - - - | 523 |
| Total - - - | 3,166 |

### *Daily Rainfall, February 16th to March 16th (inclusive)* 1896.

| —— | Belmont (Springs). | High Rid. | Ent-wistle. | —— | Belmont (Springs). | High Rid. | Ent-wistle. |
|---|---|---|---|---|---|---|---|
| 1896. | | | | 1896. | | | |
| Feb. 16 - | — | — | — | Mar. 2 - | 0·13 | 0·09 | 0·05 |
| „ 17 - | — | — | — | „ 3 - | 0·35 | 0·22 | 0·34 |
| „ 18 - | — | — | — | „ 4 - | 0·14 | 0·23 | 0·14 |
| „ 19 - | — | 0·04 | 0·03 | „ 5 - | 0·30 | 0·14 | 0·31 |
| „ 20 - | 0·4 | — | 0·04 | „ 6 - | 0·23 | 0·21 | 0·30 |
| „ 21 - | 0·26 | 0·25 | 0·25 | „ 7 - | 0·27 | 0·20 | 0·31 |
| „ 22 - | 0·18 | 0·19 | 0·12 | „ 8 - | 1·18 | 0·88 | 1·03 |
| „ 23 - | — | — | — | „ 9 - | 0·17 | 0·06 | 0·04 |
| „ 24 - | — | — | — | „ 10 - | 0·04 | 0·07 | 0·05 |
| „ 25 - | — | — | — | „ 11 - | 0·40 | 0·31 | 0·32 |
| „ 26 - | | — | — | „ 12 - | 0·24 | 0·15 | 0·11 |
| „ 27 - | — | — | — | „ 13 - | 0·01 | 0·03 | 0·03 |
| „ 28 - | 0·23 | 0·18 | 0·20 | „ 14 - | 0·95 | 0·56 | 0·66 |
| „ 29 - | 0·42 | 0·51 | 0·36 | „ 15 - | 0·01 | 0·01 | 0·03 |
| Mar. 1 - | 1·32 | 0·18 | 1·38 | „ 16 - | 0·63 | 0·52 | 0·57 |

### *Notes on the Characters of the Gathering Grounds.*

*Entwistle Gathering Ground.*—This is a moorland gathering ground, but peat is not very abundant, either superficially or in depth, except on the higher and flatter portions of the drainage area. The vegetation is chiefly coarse pasture grass, but in many places heather and moss grow. There is not a great amount of spring water, the main source of supply being from surface drainage. The surface water is not exceptionally peaty under ordinary conditions of rainfall, but in storm time a large amount of peaty water enters the supply. The drainage from the soil is rapid, but on some portions of the gathering ground the rain stagnates to a certain extent in peaty land. The surface soil rests on millstone grit.

*Springs Gathering Ground.*—This gathering ground is much more peaty than the above. There is less grass and more heather and moss. Areas exist where the rain stagnates in peat. The soil is not so well drained on this gathering ground as in the case of Entwistle, and there is less spring water, and the water derived from surface drainage is more peaty.

The surface soil rests on millstone grit.

*High Rid Gathering Ground.*—The gathering ground of this system of water supply differs in a marked manner from the ones already described. Nearly the whole of it is covered with grass, and the soil generally is only slightly peaty in character. There are no moorland streams, the supply being obtained from springs. The water is piped into a common channel, which discharges into High Rid Reservoir.

The surface soil rests on millstone grit.

### *Conditions found to exist on the Gathering Ground on March 16th, 1896.*

The daily rainfall from February 16th to March 16th is given in an accompanying table. It is to be noted that the rainfall for March 14th and 16th was considerably above the average, and that on the date of visit (March 16th) the streams were found to be running fuller than normal.

Lacmoid was used as usual to test the reaction of the various waters.

*Entwistle System.*—The water in Entwistle Reservoir was tested at various points, and appeared to contain only traces of acid. Owing to the wind and rain the water was much discoloured—the clay from the bed of reservoir being apparently the cause of the turbidity. Cadshaw Brook, the main source of the water-supply, was distinctly acid in reaction. Another and smaller stream entering the reservoir near Cadshaw Brook was neutral. Two small streams draining peaty land on one side of the reservoir were acid. All these streams were running fuller than normal.

*Springs System.*—The water in Springs and Dingle Reservoirs was distinctly acid in reaction, as was also the peaty water in the moorland stream, which is the only source of supply to this system.

*High Rid System*—.The water in High Rid Reservoir was neutral. The spring water which supplies this reservoir was also neutral in reaction.

Samples of water were collected for more detailed examination from Entwistle Reservoir, the spring water to High Rid Reservoir, Cadshaw Brook, and Springs Reservoir. Briefly, the chemical analyses gave the following results. The spring water was neutral and free from plumbo-solvent ability, Entwistle Reservoir water contained trace of acid and dissolved lead to an inconsiderable extent, Cadshaw Brook was acid and acted appreciably on lead, and the water from Springs Reservoir was distinctly acid and had a considerable plumbo-solvent ability. The bacteriological results were of interest. The most acid water (Springs Reservoir) contained fewest germs, and Cadshaw Brook contained fewer germs than Entwistle Reservoir, although the former was a distinctly acid water and the latter practically neutral. The neutral spring water contained so many germs that their estimation was not undertaken. Possibly in this latter case some surface water from cultivated land may enter the supply. It was noticed during the bacteriological investigation of the Bentham Water Supply that the acid peat pools contained fewer germs than the brooks into which they drained, the brooks containing a mixture (neutral) of spring and peaty water.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the Observed Characters of the Gathering Ground.*

*Entwistle System.*—The two small streams entering the side of Entwistle Reservoir, which were found to be acid in reaction, drain land unmistakably peaty in character. Cadshaw Brook, which was acid and dissolved lead to an appreciable extent, drains land which in parts is decidedly peaty, where the rain stagnates in the soil. The small neutral moorland stream entering the reservoir near Cadshaw Brook is said to drain land where there is less peat, better drainage of the soil, and possibly more spring water.

The nearly neutral condition of Entwistle Reservoir may be accounted for in the following way. The bed of the reservoir is composed largely of clay and sand, and during storms the water becomes very turbid in consequence. Possibly this may have some neutralising effect. It is not improbable that Cadshaw Brook is neutral under ordinary conditions of rainfall. The small neutral stream (above alluded to) may supply the reservoir with water which has an acid neutralising ability.

*Springs Systems.*—As has been already shown, Springs and Dingle Reservoir contain acid water, and practically their only source of supply is from a moorland stream, which is also acid. The acidity of this stream appears to be traceable to the peaty character of the soil covering the drainage area. Not only is the soil exceptionally peaty, but the drainage therefrom is not very rapid and the conditions are such that the rain can stagnate in peaty and mossy beds and in marshy places. Moreover, there does not seem to be much spring water in this supply.

*High Rid System.*—The neutral condition of High Rid Reservoir is to be accounted for by the fact that there is very little surface water —and what there is, is not distinctly peaty—gaining access to the reservoir, the main source of supply being from hillside springs which are piped together, and enter the reservoir by a closed and "common" channel.

In conclusion, it is to be noted that the quality, as regards acidity an plumbo-solvent ability of the water in Entwistle and Springs Reservoirs, might in all probability be improved by some arrangement for excluding storm water from the supply.

### BOLTON CORPORATION WATERWORKS.

*Table 7.—Chemical and Bacteriological Results.*

| Description of the Sample of Water. | Acidity. | | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | | Number of Micro-Organisms in 1 c.c. of the Water. |
|---|---|---|---|---|---|---|---|---|---|
| | Reaction with Lacmoid. | In Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required o neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. | |
| Entwistle Reservoir water, March 17th, 1896. | ? Trace acid. | ? Trace acid. | | | ? Traces | | | | 2640 |
| "Conjoint" spring water, main supply to High Rid Reservoir, March 17th, 1896. | Neutral | Neutral | 0·0 | 0·0 | ·0 | 0·0 | 0·0 | 0·00 | The colonies were too numerous, and the liquefaction of the gelatin too great, to alow of accurate counting. |
| Cadshaw Brook, main supply stream to Entwistle Reservoir, March 17th, 1896. | Acid | 0·36 | 0·1 | 0·1 | 0·2 | 0·2 | 0·4 | 0·20 | 962 |
| Springs Reservoir water, March 17th, 1896. | Acid | 0·48 | 0·1 | 0·2 | 0·3 | 0·4 | 0·1 | 0·25 | 60 |

## Survey No. 8.

### BRADFORD CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The water supply of the Bradford Corporation is, with the exception of the Manywells supply, which is spring water, derived from high moorland, and is given by two separate services, known as the high level and low level services respectively.

*High Level Supply.*—The high level sources of supply lie about 10 miles west of Bradford, in the valleys of the Denholme Beck and the River Worth, both tributaries of the River Aine. The principal streams taken are: Stubden Beck and Foreside Beck in the Denholme Valley, and Bond Clough, Ray Clough, Greenholes Clough, Hardnese Clough, Dup Dyke, Paul Clough, Sun Hill Clough, Nan Scar Beck, Holden Clough, Harden Clough, Stoney Hill Clough, and Foster Dyke, in the valley of the River Worth. There are two reservoirs on the gathering ground—Thornton Moor and Stubden.

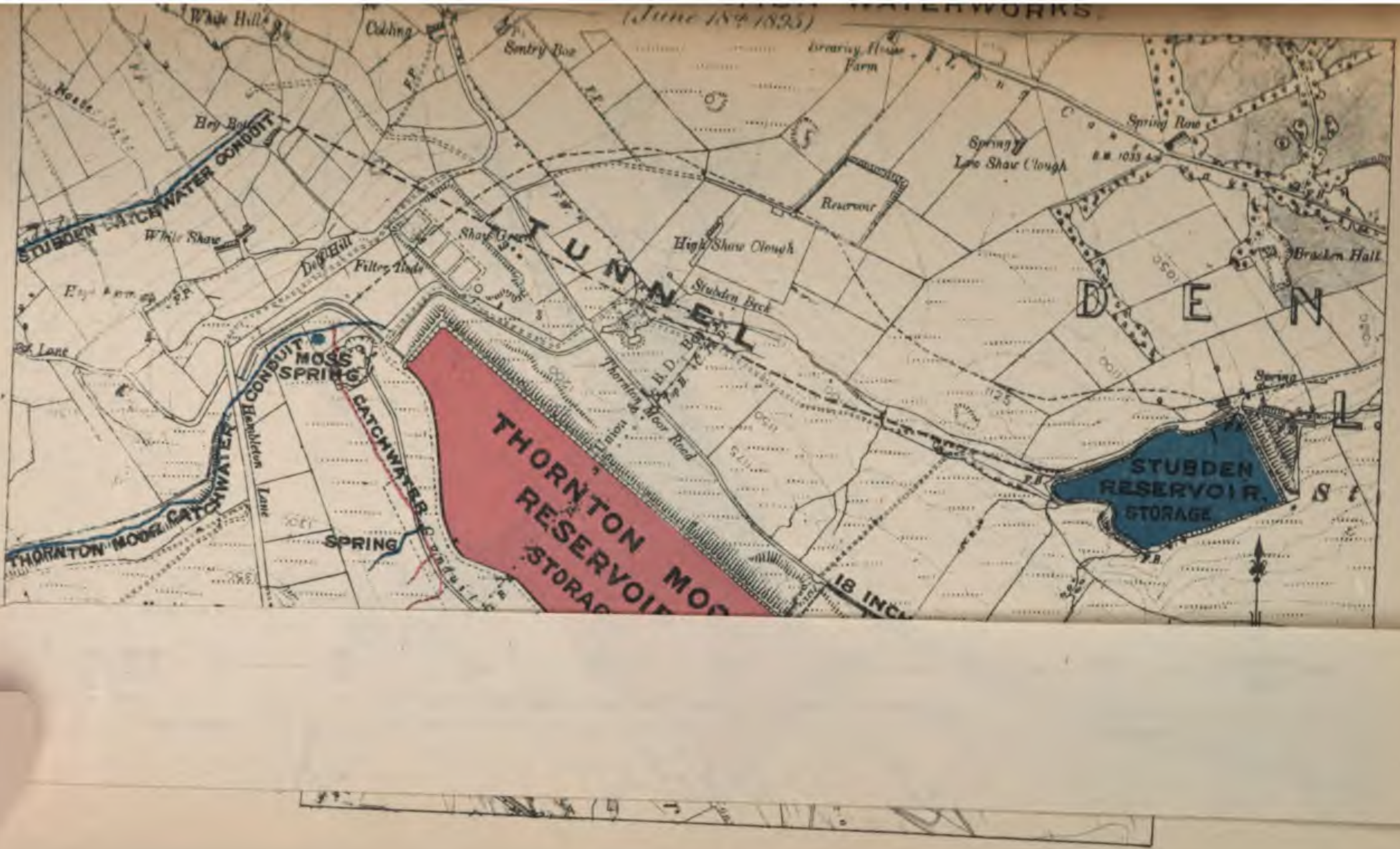
*Thornton Moor Reservoir.*—This reservoir is situated at a height of 1,241 feet above sea level. An embankment extends along the north-west, north-east, and south-east sides of the reservoir. A number of iron pipes convey water from the surface drainage of peat into the south-west side of the reservoir. The waters of the cloughs and becks in the Worth Valley are collected and carried to the reservoir in a large catchwater conduit which extends westwards for a distance of 3¼ miles, and which also intercepts the water flowing in a northerly direction from off the Oxenhope Moors. The water from this conduit, before discharging into the western angle of the reservoir, receives water from Moss Spring and from a small catchwater. The water from Moss Spring is large in amount, but is in private hands, and only the surplus water is available for the Bradford supply. The water from the catchwater above alluded to is not great in amount, except in storm time. The water from Thornton Moor reservoir is treated with pure carbonate of lime—about three grains to the gallon—and is then filtered through sand and gravel. After leaving the filter beds the water is carried in an 18-inch iron main to Brayshaw Reservoir, and from thence to near Bierley, where it joins the water from Stubden and Horton Bank Reservoirs. The mixed water is carried to Idle Hill Reservoir, to the high level zone of supply within the borough, and to many of the out townships.

Provision exists for the exclusion of storm water from the waterworks.

*Stubden Reservoir.*—This reservoir is situated at a height of 1,028 feet above sea level, and is supplied with water from Stubden Beck and Fireside Beck and from a catchwater conduit which runs for a distance of 4 miles, and nearly parallel with Thornton Moor catchwater, and collects the water draining from the lower slopes of Oxenhope Moor. The water from Stubden Reservoir is not filtered, and is carried by an 18-inch iron main to Horton Bank Reservoir, and joins the Thornton Moor water near Bierley.

Storm water can be excluded from the waterworks.

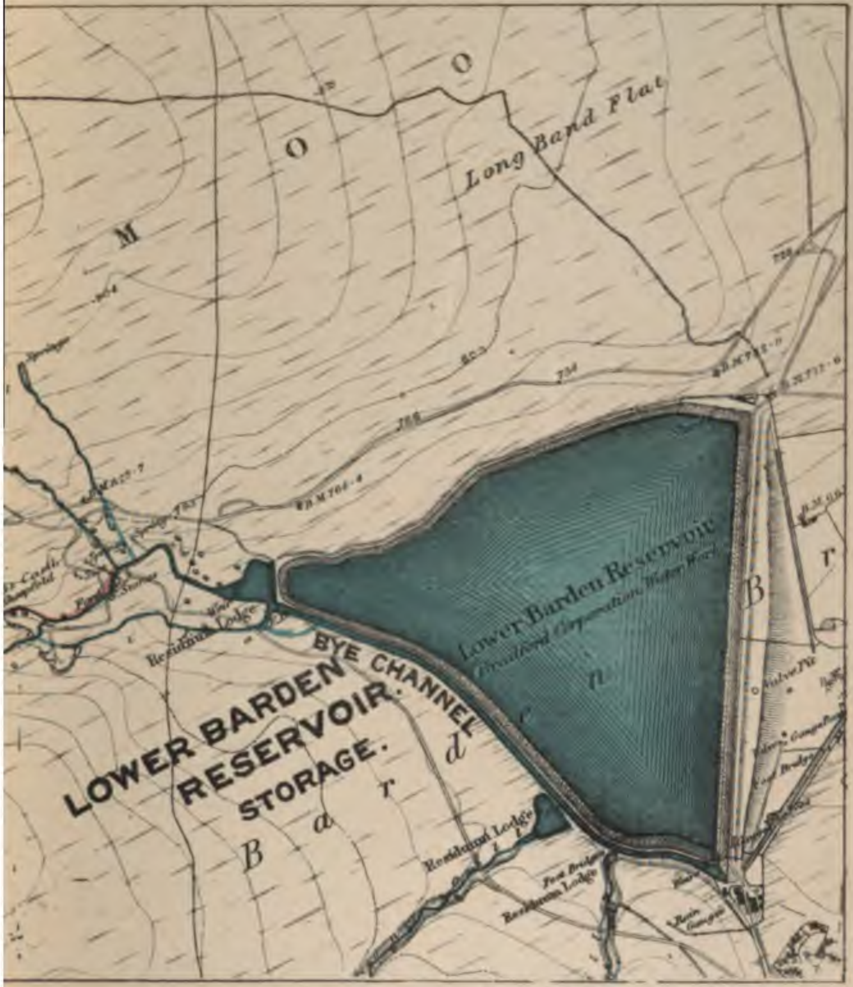
*Low Level Service.*—The low level supply is obtained from Barden Moor, in the Wharfe Valley, 20 miles N.W. of Bradford. There is



WATERWORKS

(June 1894/1895)

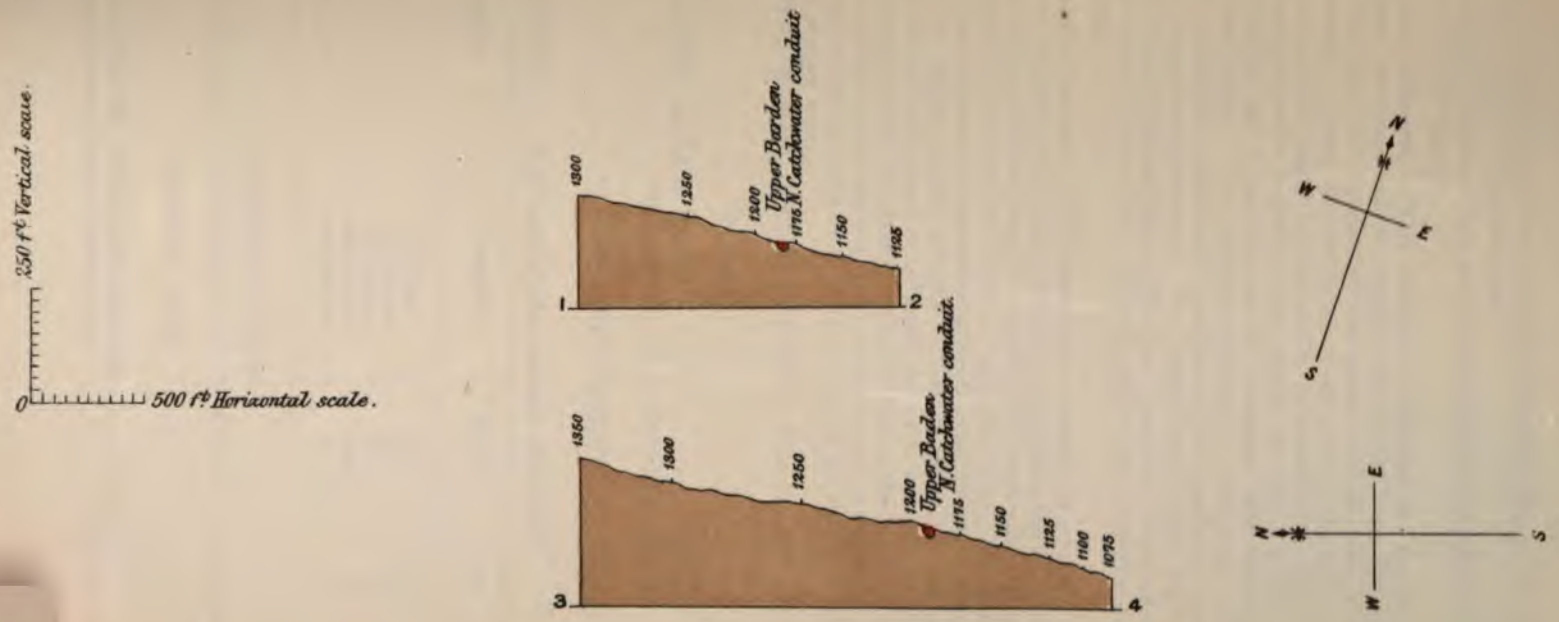
RKS.



E.Weller & Grahams, Ltd Litho. London.

2000 5280 Feet
1 Mile

**BRADFORD CORPORATION WATER WORKS.** *Plan showing sectional view of gathering ground along certain lines marked 1,2 and 3,4, on accompanying 6" Ordnance Map. The points of the compass show the direction in which these lines run.*



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also a supply from Burnsall and from Draughton Chelker Reservoir, but only the Barden supply will be described.

*Barden Supply.*—There are two reservoirs on the collecting ground, viz., Upper and Lower Barden,

*Upper Barden Reservoir.*—This reservoir is situated at a height of 1,170 feet above sea level, and is supplied with water from Padmire Sike and Yethers Gill, which enter the reservoir at its S.W. and N.W. angles respectively. Along the north and south sides of the reservoir are bye-channels. The north bye-channel is connected with Yethers Gill and with a catchwater conduit which extends for over a mile in a northerly direction, and it receives also the drainage from moorland known as The Whams. The south bye-channel is connected with Padmire Sike, and with a catchwater conduit which extends for about half a mile in a southerly direction. The water from Upper Barden Reservoir flows down Barden Beck to the lower reservoir, receiving on its way water from Pitshaw Dyke, Kittlety Sike—two streams—and Cross Gill Dike.

*Lower Barden Reservoir.*—This reservoir is situated at a height of 697 feet above sea level, and is supplied with water from Barden Beck and from Far Long and Near Long Gills on its south-west side. There is a bye-channel on the south-west side of the reservoir. The water from Lower Barden is carried in a conduit to the Gilstead filters, receiving on its way the waters of nine streams or becks, and after passing through beds of sand and gravel at Gilstead, the water is conveyed in a conduit to Heaton Service Reservoir for distribution in the borough.

Apart from filtration, the Barden water is not treated in any way.

Storm water can be excluded from the waterworks by means of bye-channels and sloping weirs.

The following notes on Bradford Corporation Waterworks are of interest :—

### *Rainfall.*

| | Inches. |
|---|---|
| Average yearly rainfall in Bradfall - - - | 32·19 |
| ” ” ” on Thornton Moor gathering ground. | 47·19 |
| ” ” ” on Barden gathering ground - | 41·54 |

### *Capacity, &c., of certain of the Storage Reservoirs.*

| Reservoir. | Capacity. | Depth. | Area. |
|---|---|---|---|
| | Gallons. | Feet. | Acres. |
| Thornton Moor - - | 175,000,000 | 27 | 46¼ |
| Stubden - - - | 93,184,000 | 53 | 11 |
| Upper Barden - - | 464,687,000 | 62½ | 53¾ |
| Lower Barden - - - | 483,404,000 | 60 | 56 |

### *Consumption of Water.*

11 million gallons per day for borough and out towns for all purposes.

### *Drainage Areas.*

| | Acres. |
|---|---|
| Thornton Moor and Stubden drainage area - - | 2,700 |
| Upper and Lower Barden drainage area - - | 3,500 |

### *Daily Rainfall on Thornton Moor Gathering Ground from May 18th,* 1895, *to June 18th,* 1895*—inclusive.*

| Date. | Inches. | Date. | Inches. |
|---|---|---|---|
| 1895. | | 1895. | |
| May 18 - - - | 0·01 | June 3 - - - | 0·01 |
| „ 19 - - - | — | „ 4 - - - | — |
| „ 20 - - - | 0·01 | „ 5 - - - | 0·01 |
| „ 21 - - - | 0·11 | „ 6 - - - | — |
| „ 22 - - - | — | „ 7 - - - | — |
| „ 23 - - - | — | „ 8 - - - | — |
| „ 24 - - - | 0·10 | „ 9 - - - | — |
| „ 25 - - - | 0·37 | „ 10 - - - | — |
| „ 26 - - - | — | „ 11 - - - | 0·08 |
| „ 27 - - - | — | „ 12 - - - | 0·13 |
| „ 28 - - - | — | „ 13 - - - | — |
| „ 29 - - - | — | „ 14 - - - | |
| „ 30 - - - | 0·03 | „ 15 - - - | — |
| „ 31 - - - | — | „ 16 - - - | — |
| June 1 - - - | 0·90 | „ 17 - - - | 0·01 |
| „ 2 - - - | 0·08 | „ 18 - - - | 0·01 |

### *Daily Rainfall on Barden Gathering Ground from July 23rd,* 1895, *to August 23rd,* 1895*—inclusive.*

| Date. | Inches. | Date. | Inches. |
|---|---|---|---|
| 1895. | | 1895. | |
| July 23 - - - | 0·27 | August 8 - - | 0·12 |
| „ 24 - - - | 0·31 | „ 9 - - | 0·07 |
| „ 25 - - - | 1·31 | „ 10 - - | 0·19 |
| „ 26 - - - | 0·57 | „ 11 - - | 0·37 |
| „ 27 - - - | 0·42 | „ 12 - - | 0·16 |
| „ 28 - - - | 0·05 | „ 13 - - | 0·63 |
| „ 29 - - - | 0·01 | „ 14 - - | 0·08 |
| „ 30 - - - | — | „ 15 - - | 0·02 |
| „ 31 - - - | — | „ 16 - - | 0·01 |
| August 1 - - | 0·05 | „ 17 - - | — |
| „ 2 - - | 0·12 | „ 18 - - | — |
| „ 3 - - | 0·34 | „ 19 - - | — |
| „ 4 - - | 0·08 | „ 20 - - | — |
| „ 5 - - | 0·01 | „ 21 - - | 0·01 |
| „ 6 - - | 0·05 | „ 22 - - | — |
| „ 7 - - | — | „ 23 - - | 0·22 |

## *Notes on the Characters of the Gathering Grounds.*

### *High Level Supply.*

*Thornton Moor Gathering Ground.*—The gathering ground is entirely composed of moorland. The surface soil is very peaty, and the depth of the peat varies from one to six feet, or even more in some places. The land on the south-west side of the reservoir is exceptionally peaty, and the rain falling on this portion of the gathering ground saturates the soil and stagnates, forming peat and bog holes and marshy places. Part of the water draining from this area is intercepted by a catchwater, and part is conducted into the reservoir by a series of iron pipes. The large catchwater conduit drains land very similiar in character to the above, but the slopes of the hills are more abrupt, the water is carried more rapidly into supply, the rain saturates the peat and stagnates therein to a less extent, and there is a considerable amount of spring water as well as of water derived from surface drainage. Moss Spring is a good example of a moorland spring supplying a large body of water. As has been explained, however, it is in private hands, and only the surplus water is available for supply.

In conclusion, and speaking generally, the following points are to be noted. The vegetation is composed of heather and moss, and in some places of rough pasture grass. The geological formation is millstone grit. The dry weather flow is small in amount, the reservoir depending for its supply largely on surface drainage water from moorland such in peat. There is a considerable tendency on portions of the collecting ground for the rain to saturate peaty soil and to stagnate. After "treatment" and filtration, and as delivered to consumers, this water is clear, pure, and soft, and exceedingly suitable for the trade of Bradford.

*Stubden Gathering Ground.*—This gathering ground differs in several important respects from the foregoing. The reservoir is supplied with water from a a catchwater conduit which drains the lower slopes of the Oxenhope moors. Here the hill slopes are more abrupt; there is much less peat; the vegetation is composed chiefly of pasture grass; the water drains more rapidly into supply; and there is a considerable amount of spring water. Unquestionably the conditions are such that the Stubden gathering ground yields a less peaty water than the adjacent Thornton Moor collecting ground.

### *Low Level Supply.*

*Barden Gathering Ground.*—The gathering ground is wholly moorland, and resembles in many respects the Thornton Moor gathering ground. The surface soil over most of the gathering ground is peat, but the peat beds thin out towards Lower Barden Reservoir, and it is only on the higher and flatter portions of the gathering ground that the depth of the peat is great. Over most of the gathering ground the slopes of the hills are steep and the drainage from the soil rapid. The amount of spring water is in excess of what is usually found on moorland collecting grounds, and in consequence the fair weather flow in the streams is above the average. The geological formation is Millstone grit. As regards the vegetation, heather and moss are abundant everywhere on the collecting ground, and there are areas here and there covered with coarse pasture grass. These remarks refer to the drainage area generally. Particularising, the following points are to be noted. The northern portion of Upper Barden collecting ground is rich in peat, the drainage from the soil is not very rapid, the peaty water is largely in excess of the spring water, and areas exist where the rain lies stagnating in peaty and marshy places. The southern portion is much more satisfactory in these respects. As regards Lower Barden, it is to be noted that Pitshaw Dike, Kittlety Sike, Cross Gill Dike, and Far Long, and Near Long Gills, all drain land which although peaty, possesses the following redeeming features. The peat beds are thin, the drainage from the soil is rapid, the hill slopes are abrupt, there is a large amount of spring water as well as of surface drainage water, and there are but few areas where the rain can stagnate in peaty and marshy places. A point of some importance is that Barden Beck, the main source of supply to Lower Barden Reservoir, runs for over a mile on a rocky and sandy bed.

It is to be noted that nine tenths of the gathering grounds from which the water is taken are high moorlands (from 600 feet to 1,500 feet above the level of the sea), and above the reach of pollution from populated districts.

### *Conditions found to exist on the Gathering Grounds on June 18th, 1895, and August 23rd, 1895.*

### *High Level Supply.—June 18th, 1895.*

The rainfall from May 18th, 1895, to June 18th, 1895, is given in an accompanying table. Owing to the preceding dry weather, the conditions were not favourable for an inspection of the collecting ground, and many of the feeders which supply the reservoirs with water under ordinary conditions of the rainfall were dry. The reaction of the various waters was tested with an alcoholic solution of lacmoid.

The water in Thornton Moor Reservoir was tested at various points, and found to be distinctly acid. The peaty water, which is led into the south-west side of the reservoir by a series of iron pipes, was dried up, but samples obtained at a later date and during storm time were very acid.

As regards the small catchwater, it was found that the water running in it was acid, and two small peat drains which supply it with water were acid, and one stream containing chiefly spring water was neutral in reaction.

Moss spring water was neutral in reaction. The large catchwater conduit which supplies the greater bulk of the water entering the reservoir was traced upwards for a considerable distance, and the water in it was found to be neutral. The peat feeders which under ordinary conditions drain into it were all dry. The only water, indeed, supplying the conduit was from springs, and this water was found to be neutral. A sample obtained at a later date from this catchwater yielded very different results, as is shown in an accompanying table. Thornton Moor Reservoir water after being treated with lime and filtered was quite neutral in reaction.

Stubden Reservoir water was found to be neutral, and the water in the catchwater conduit supplying this reservoir had a similar reaction.

### *Low Level Supply.—August 23rd, 1895.*

The rainfall previous to August 23rd is given in an accompanying table. Owing to the preceding dry weather the water from surface drainage was very small in amount, and in consequence the conditions were not very favourable for the inspection of the gathering ground.

Upper Barden Reservoir water was tested at various points, and found to be acid in reaction. The north bye-channel contained acid water, and six streams supplying it with water draining from very peaty land were all acid. The north catchwater conduit was also acid, and so was the water in Yethers Gill. The south bye-channel contained neutral water, and the water in Padmire Sike and in the south catchwater conduit was also neutral. Barden Beck was traced downwards, and the water, which at first was distinctly acid, gradually became less and less acid, until and just before discharging into Lower Barden Reservoir it ceased to contain even traces of acid. Pitshaw Dike and Kittlety Sike, which flow in Barden Beck, were neutral. The water in Lower Barden Reservoir was neutral, as was also the water in Far Long and Near Long Gills. The outflow water from Lower Barden Reservoir and the water joining the Barden supply from Burnsall gathering ground was neutral in reaction.

It is to be noted that under laboratory conditions of experiment moorland waters which give a neutral reaction with lacmoid do not dissolve lead, but those which give an acid reaction possess plumbo-solvent ability.

Samples of water were collected for more detailed examination from the following sources:—Thornton Moor Reservoir water (before and after treatment), Moss Spring water, Stubden Reservoir, Upper and Lower Barden Reservoirs, and Upper Barden north bye-channel. Samples of water were also obtained from Bradford town mains (high and low level services), Thornton Moor catchwater conduit—two samples, and from iron pipes discharged into south-west side of Thornton Moor Reservoir—four samples. The results are given in an accompanying table, and may be briefly described as follows:—

The samples from Bradford town water from the high and low level services were neutral, and did not dissolve lead, and were harder than is usually found in the case of moorland waters. Thornton Moor Reservoir water was distinctly acid, and dissolved lead to a considerable extent. After treatment and filtration, however, the water was neutral and free from plumbo-solvent ability, and its hardness was much increased.

Stubden Reservoir and Moss Spring waters were neutral, and did not dissolve lead. A mixture of equal parts of Thornton Moor Reservoir water and Moss Spring water yielded a water practically free from acidity and plumbo-solvent ability.

As has been stated Thornton Moor catchwater conduit contained neutral water on June 18th. A sample obtained on July 2nd from the same source, and stated to be storm water, was neutral and free from action on lead. It is improbable, however, that this sample represented storm water, because another sample received a few days after, and which was peaty in colour, was found to be very acid and to act on lead in the most marked way. The water from the south-west side of Thornton Moor Reservoir was dry on June 18th, but samples received at a later date, and during storm time, was extremely acid, and dissolved lead to a very great extent. The water from Lower Barden Reservoir and from the Burnsall supply was neutral and free from plumbo-solvent ability. The water from Upper Barden Reservoir and its northern bye-channel was slightly acid and acted on lead to an inconsiderable extent. It is to be noted that Burnsall water, which contains a large amount of spring water, was much harder than the more peaty waters, *e.g.*, Upper Barden Reservoir water.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

### *High Level Supply.*

*Thornton Moor Gathering Ground.*—The characters of this drainage area, which have been already described, are of such a nature that it is not surprising to find that the water stored in Thornton Moor Reservoir is acid. It remains, however, to discuss, among other things, why the large catchwater conduit contained neutral water on June 18th. Briefly, on that date the water derived from surface drainage was dry, and only neutral spring water was gaining access to the waterworks. It is true that a sample obtained at a later date, which was stated to be storm water, was also neutral, but this sample, to judge by its appearance, did not truly represent storm water. A sample obtained a few days later, which was evidently flood water, and which was much discoloured with peaty matter, was very acid. It seems, then, that this catchwater conduit contains neutral water during its dry weather flow and acid water during storm time.

That the water in the small catchwater was acid is readily understood, since it has been shown that water derived from the drainage of very peaty soil was gaining access to it. It is of particular interest to note that the water which drains from the south-west side of the reservoir was dry on June 18th, but as soon as rain fell a very acid peaty water was discharged into the waterworks. The result of the experiment, in which equal parts of neutral, moss, spring, and acid reservoir water were mixed, is of interest, as showing that moorland springs are usually not only neutral, but possessed of some acid neutralising ability.

*Stubden Gathering Ground.*—It was shown that this collecting ground differed in many important respects from the foregoing, and it was noted in particular that the spring water was large in amount, and the water derived from the drainage of peat was very much less than in the case of the Thornton Moor gathering ground. Correspondingly, the Stubden water was found to be neutral and free from action on lead.

## *Low Level Supply.*

*Upper Barden Gathering Ground.*—The slight acidity of the reservoir water is easily accounted for. Yethers Gill and the north bye-channel and catchwater drain land unquestionably peaty, and the water entering the waterworks on this side of the reservoir was found to be acid. Possibly Padmires Sike, on the south side of the reservoir, may contain acid water in storm time. This is less likely to be the case with the south catchwater, as it contains a considerable amount of spring water. That Upper Barden Reservoir was not more acid appears to be due to the dry weather flow of the feeders being fairly abundant, owing to the presence on the gathering ground of a considerable number of hillside springs.

*Lower Barden Gathering Ground.*—The chief supply to Lower Barden is from the Upper Reservoir, but there are a number of moorland streams which also supply the waterworks. Lower Barden Reservoir was found to be neutral, and all its feeders had a similar reaction. The reason of this neutral condition of the various waters seems to be traceable to the more favourable conditions prevailing on the lower collecting ground. Thus the peat is thinner, the hill slopes are more abrupt, the drainage from the soil is more rapid, and the peaty water is less and the spring water more in amount on the lower, as compared with the higher collecting ground. The gradual change of reaction observed in Barden Beck is of especial interest, and may be explained in the following way. Possibly the mere delay of the water in its passage between the two reservoirs may have had some influence, and probably the flow of the water along the rocky and sandy bed of the stream affected the acidity, but most likely of all the neutral spring water from Pitshaw Dike and Kittlety Sike possessed some acid neutralising ability.

In conclusion, and speaking generally, it is to be noted that the chemical results bore out in a remarkable way the observed characters of the gathering grounds.

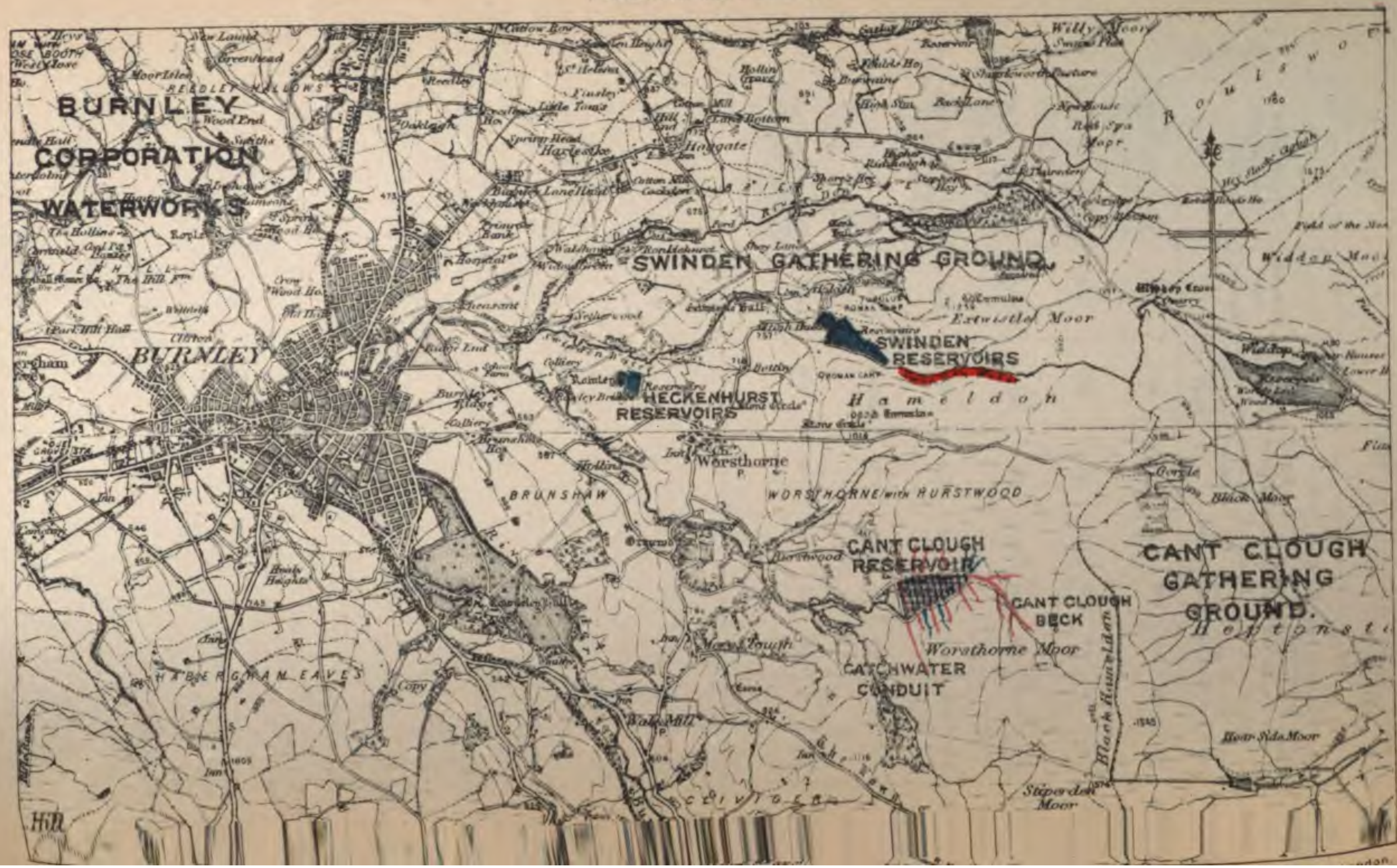
## BRADFORD CORPORATION WATERWORKS.

### *Table* 8.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ parts per 100,000). | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | June 12th, 1895. Bradford town water. High level service. | Neutral | Neutral | 9·8 | 0.0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 2 | June 12th, 1895. Bradford town water. Low level service. | Neutral | Neutral | 10·08 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 3 | June 19th, 1895. Thornton Moor Reservoir water. Before "treatment." High level supply. | Acid | 0·42 | 3·92 | 0·3 | 0·6 | 0·7 | 0·8 | 0·8 | 0·64 |
| 4 | June 19th, 1895. Thornton Moor Reservoir water. After "treatment" and filtration. High Level supply. | Neutral | Neutral | 9·94 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | June 19th, 1895. Moss Spring water, Thornton Moor. High level supply. | Neutral | Neutral | 3·36 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | June 19th, 1895. Stubden Reservoir water. High level supply. | Neutral | Neutral | 8·68 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | June 21st, 1895. Equal parts of samples 3 and 5 mixed together and allowed to stand overnight. | ? trace acid | ? trace acid | — | — | — | ? Faint traces. | | | |
| | July 2nd, 1895. Water from Thornton Moor Catchwater conduit at point of entrance into Thornton Moor Reservoir. High level supply. The sample was stated to be "storm water." | Neutral | Neutral | — | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | July 5th, 1895. Same as above (No. 8). This sample, however, appeared to be unquestionably "storm water." | Acid | 0·90 | — | 1·5 | 2·0 | 2·0 | 2·5 | 2·5 | 2·10 |
| | July 2nd, 1895. Water from iron pipe No. 1 discharging into S.W. side of Thornton Moor Reservoir. On June 18th (date of visit) this water was dry. High Level supply. | Acid | ·54 | — | 0·2 | 0·6 | 0·6 | 0·6 | 0·6 | 0·52 |
| 1 | Same as above (No. 10), but the water was taken from iron pipe No. 2. | Acid | 1·38 | — | 2·0 | 3·0 | 3·0 | 3·0 | 3·0 | 2·80 |

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ parts per 100,000). | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 12 | Same as above (No. 10), but the water was taken from iron pipe No. 3. | Acid | 1·56 | — | 2·0 | 3·0 | 3·0 | 3·5 | 3·5 | 3·00 |
| 13 | Same as above (No. 10), but the water was taken from iron pipe No. 4. | Acid | 1·50 | — | 2·0 | 3·0 | 3·0 | 3·0 | 3·0 | 2·80 |
| 14 | Aug. 24th, 1895. Lower Barden Reservoir water. Low level supply. | Neutral | Neutral | 4·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 15 | Aug. 24th, 1895. Upper Barden Reservoir water. Low level supply. | Acid | 0·30 | 2·7 | 0·0 | 0·1 | 0·0 | 0·2 | 0·2 | 0·12 |
| 16 | Aug. 24th, 1895. Burnsall water (joins Barden conduit). Low level supply. | Neutral | Neutral | 7·7 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 17 | Aug. 24th, 1895. Water from bye-channel, north side of Upper Barden Reservoir. Low level supply. | Acid | 0·18 | 2·1 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 | 0·10 |

(March 26th 1896)



## Survey No. 9.

### BURNLEY CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland gathering grounds at Cant Clough and Swinden, about four miles from Burnley. Another source of supply is from hillside springs in the same neighbourhood.

*Cant Clough Gathering Ground.*—Cant Clough Reservoir obtains its chief supply of water from Cant Clough Beck, which drains a large area of moorland. Other and smaller mountain streams enter the sides of this reservoir, while a considerable amount of water drains off 100 acres of moorland into a catchwater conduit which enters the reservoir near its embankment. The unfiltered water from Cant Clough Reservoir is conveyed into a reservoir (Heckenhurst) situated at a lower level, which also receives the water from Swinden Reservoir (No. 2), and from certain hillside springs, and which supplies the low levels of the town.

There is no arrangement for excluding storm water from the waterworks, and the whole of the water draining from this gathering ground has to pass through the reservoir; in consequence after a flood the water in the reservoir is slightly fouled. Land has recently been purchased by the corporation for the laying down of filter beds, and it is proposed in the future to filter the water from Cant Clough Reservoir. Cant Clough Reservoir embankment is ballasted with broken stones, and pitched with heavy ashler pitching. The inside of the reservoir is not covered with broken stone.

*Swinden Gathering Ground.*—Here there are two reservoirs for domestic use, Swinden No. 1, and Swinden No. 2. The latter, which is fed entirely from Swinden No. 1, sends its water (unfiltered) to Heckenhurst Reservoir, which, as has been already mentioned, receives also the water from Cant Clough Reservoir and from hillside springs, and supplies the low levels of the town. A separate and independent main from Swinden Reservoir No. 2 goes direct to the town to supply the high-level service. There is practically only one source of water supply to Swinden Reservoir No. 1, and this is from Swinden Brook, which drains a large tract of moorland. A watercourse runs along one side of Swinden Reservoir No. 1, and by its means storm water can be excluded from the supply. The whole of the inside of Swinden Reservoir is ballasted with broken stones, and the slopes of the embankment are pitched with heavy ashler blocking.

"*Springs*" *Supply.*—This source of supply is from hillside springs, and in each case, as the water issues from the ground, it is received into a chamber, and conveyed from thence to a central chamber, from whence the water is carried in iron pipes to Heckenhurst Reservoir.

The water from Heckenhurst Reservoir, which contains a mixture of Cant Clough and Swinden waters with the spring water, is conveyed, without being filtered, to the low levels of the town.

The following notes on Burnley Corporation Waterworks are of interest:—

### *Rainfall.*

| | | |
|---|---|---|
| Average yearly rainfall in Burnley - - | 40·65 | inches. |
| " " on Cant Clough gathering ground - - - | 41·67 | " |
| " " in Swinden gathering ground | 43·84 | " |

### *Capacity of the Reservoirs.*

| Reservoir. | Capacity. | Top Water Level. | Depth. | Area. | | |
|---|---|---|---|---|---|---|
| | Gallons. | Feet. | Feet. | A. | R. | P. |
| Cant Clough - - | 250,000,000 | 924 | 61 | 38 | 0 | 0 |
| Swinden No. 1 - - | 116,000,000 | 802 | 70 | 18 | 3 | 21 |
| Swinden No. 2 - - | 34,000,000 | 780 | 38 | 4 | 0 | 0 |
| Heckenhurst Reservoir - | 20,000,000 | 605 | 20 | 4 | 2 | 15 |

### *Drainage Areas.*

| | | |
|---|---|---|
| Cant Clough | - | 1,000 acres. |
| Swinden | - | 660 acres (domestic), 985 acres (compensation). |

### *Yield of Water and Consumption of Water.*

*Cant Clough Supply—Swinden Supply.*—The yield from the Cant Clough and Swinden gathering ground cannot be accurately given, the water not being gauged at the inlets. The amount drawn for consumption for the year ending March 25th, 1896, was, on an average, daily, 1,447,518 gallons from Swinden Reservoir, and 773,000 gallons from Cant Clough Reservoir.

"*Springs*" *Supply.*—The average daily yield from the springs for the year ending March 25th, 1896, was 573,943 gallons. The consumption for the above period was 23·66 gallons per head per day of the population, for trade and domestic purposes combined, or 20·73 for domestic use alone.

### *Daily Rainfall from February 26th, 1896, to March 26th on Gathering Ground.*

| 1896. | Swinden. | Cant Clough. | 1896. | Swinden. | Cant Clough. |
|---|---|---|---|---|---|
| | Inches. | Inches. | | Inches. | Inches. |
| Feb. 26th - | 0·00 | 0·00 | Mar. 13th - | 0·49 | 0·44 |
| „ 27th - | 0·23 | 0·16 | „ 14th - | 0·01 | 0·01 |
| „ 28th - | 0·27 | 0·24 | „ 15th - | 0·46 | 0·44 |
| „ 29th - | 0·65 | 0·68 | „ 16th - | 0·03 | 0·05 |
| Mar. 1st - | 0·04 | 0·05 | „ 17th - | 0·10 | 0·10 |
| „ 2nd - | 0·47 | 0·45 | „ 18th - | 0·00 | 0·00 |
| „ 3rd - | 0·35 | 0·15 | „ 19th - | 0·14 | 0·11 |
| „ 4th - | 0·14 | 0·15 | „ 20th - | 0·14 | 0·12 |
| „ 5th - | 0·17 | 0·15 | „ 21st - | 0·01 | 0·02 |
| „ 6th - | 0·38 | 0·48 | „ 22nd - | 0·01 | 0·01 |
| „ 7th - | 0·82 | 0·76 | „ 23rd - | 0·00 | 0·00 |
| „ 8th - | 0·06 | 0·05 | „ 24th - | 0·04 | 0·04 |
| „ 9th - | 0·02 | 0·03 | „ 25th - | 0·50 | 0·44 |
| „ 10th - | 0·25 | 0·20 | „ 26th - | 0·38 | 0·37 |
| „ 11th - | 0·03 | 0·02 | | | |
| „ 12th - | 0·00 | 0·00 | | 6·19 | 5·68 |

## *Notes on the Characters of the Gathering Grounds,*

*Cant Clough and Swinden Gathering Grounds.*—These are moorland gathering grounds, and they do not differ from each other sufficiently to need a separate description.

In the neighbourhood of the reservoirs the vegetation is chiefly composed of rough pasture grass, and the soil is more or less peaty. Higher up on the flatter portions of the gathering ground heather and moss are abundant, and the soil is exceptionally peaty. The slopes of the hills are such as to allow of efficient drainage of the land, but areas also exist where the rain is not is not carried rapidly away, and here the rain saturates and lies stagnant in the peaty soil. These areas are to be found chiefly on the higher and flatter portions of the gathering grounds, and it is in these places that moss and heather and beds of peat and marshy land are to be found. Besides the water derived from surface drainage, there is a considerable amount of spring water.

"*Springs*" *Supply.*—This supply is from hillside springs, and affords a good example of moorland spring water unmixed with surface water which is yet comparatively soft.

Speaking in general terms, the geological formation is carboniferous sandstone with boulder clay mixed with drift limestone in the valleys.

## *Conditions found to exist on the Gathering Grounds on March 26th,* 1896.

The rainfall from February 26th to March 26th (inclusive) is given in an accompanying table. It is to be noted that there was heavy rain before March 26th, and the streams in consequence were running fuller than normal.

Lacmoid was used to test the reaction of the various waters. Experiments show that when a water gives a neutral reaction with this indicator, it will not dissolve lead to any appreciable extent under laboratory conditions of experiment.

*Cant Clough System.*—The water in Cant Clough Reservoir was tested at various points, and it contained only traces of acid. Cant Clough Beck, which, owing to the heavy rains, contained much surface water, was distinctly acid. This mountain stream was traced upwards towards its source for a considerable distance, and it was found that it divided into two separate streams, each of which was acid. Some small feeders which enter Cant Clough Beck and drain peaty land were also tested, and they were found to be acid. Along the right bank of the reservoir a number of small streams were tested. Four of these were neutral and four acid. The acid streams appeared to contain chiefly peaty water and the neutral ones spring water, or a mixture of peaty and spring water. The streams entering the left side of the reservoir were small; out of six tested four were acid. On this side of the reservoir a good example of one of the so-called "ochre" springs so common on moorland gathering ground was found. The water, as appears to be the rule, was neutral. The catchwater conduit entering the reservoir near its embankment contained water which was distinctly acid. The same remark applies to a mountain stream draining peaty land which enters the reservoir near Cant Clough Beck. Speaking in general terms, and so far as could be ascertained, those streams which contained much surface peaty water were acid, and those which contained spring water, or a mixture of spring water with a small amount of peaty water, were neutral.

*Swinden System.*—Swinden Reservoirs (No. 1 and No. 2) contained neutral water. Swinden Brook was, however, acid, and contained much peaty water. This water, however, does not enter Swinden Reservoir during flood time, owing to the provision of a storm watercourse.

. "*Springs*" *Supply.*—The spring water was neutral in reaction.

The water in Heckenhurst Reservoir, which contains a mixture of spring water and Cant Clough and Swinden waters, was neutral.

Various samples of water were collected for more detailed examination. The results are given in an accompanying table, but briefly they may be described as follows:—

The water from "springs" supply, from the outlet from Swinden Reservoir (No. 1) and from the "Lower" Reservoir, where the various waters mix, was neutral, and had no action on lead. Cant Clough Reservoir water was faintly acid, and dissolved lead only to a very small extent. Swinden Brook was acid, and had a very appreciable plumbo-solvent ability. Cant Clough Beck was decidedly acid, and dissolved lead in a marked way. It is important to note, however, that an equal mixture of the spring water with Cant Clough Beck (flood water) yielded, when tested for acidity and plumbo-solvent ability, practically negative results. Samples of Cant Clough and Swinden water obtained at a later date, and under ordinary conditions of rainfall, yielded, on examination, interesting results. Both waters now contained only traces of acid and acted only faintly on lead.

The bacteriological examination of the water yielded the following results:—The outlet water from Swinden Reservoir No. 1 contained 960, Cant Clough Reservoir water 225, Swinden Brook 414, and Cant Clough Beck 960 micro-organisms per c.c. respectively.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference, among other things, to the observed Characters of the Gathering Ground.*

It is especially to be noted that the conditions found to exist on March 26th, 1896, were not normal as regards the rainfall. Owing to the heavy rains, a large amount of surface water was entering the waterworks, and many small streams were running full, which, under ordinary conditions, are said to contain little or no water.

*Cant Clough System.*—It is of interest to note the nearly neutral condition of, and almost entire absence of, plumbo-solvent ability in the water of Cant Clough Reservoir as compared with the great acidity and plumbo-solvent ability of the water in its main inlet feeder, Cant Clough Beck. The difference in the quality of the two waters may be accounted for in the following way:—There can be little doubt that the condition of the water in Cant Clough Beck on March 26th was due to the large amount of surface water draining into the supply from peaty land as a consequence of the heavy preceding rains. A sample of water obtained at a later date, and under ordinary conditions of rainfall—when the surface peaty water would be much reduced in amount and the spring water relatively increased—was found to resemble the water in Cant Clough Reservoir, being almost absolutely free from acidity and plumbo-solvent ability. It is not unlikely that the other streams which on March 26th were acid, would, like Cant Clough Beck, be neutral under ordinary conditions. That Cant Clough Reservoir water was practically neutral and free from plumbo-solvent ability seems to be due to the fact that it is only in storm time that the streams which supply the reservoir with water are acid. Nevertheless, a large amount of acid water apparently does enter the reservoir, and it requires explanation why this water does not influence the reservoir water to a greater extent. Its small amount relative to the total bulk of water might be considered sufficient explanation, but it is of interest to note also that experiments show that the tendency is for an acid water to undergo some diminution of its acidity under conditions of storage. Further, it is quite possible that during drought the feeders supply the reservoir with water which is not only neutral, but possessed of some acid neutralising ability.

*Swinden System.*—The above remarks apply very closely in the case of this water supply. Swinden Brook was found to be acid and Swinden Reservoir neutral on March 26th. Swinden Brook, examined at a later date and under more favourable conditions as regards the rainfall, was nearly neutral. The neutral condition of Swinden Reservoir as compared with the slightly acid state of Cant Clough Reservoir may be traced to the smaller amount of acid in Swinden Brook as compared with Cant Clough Beck, and also to the provision of a storm watercourse in connexion with the former system of water supply.

In concluding the remarks on Cant Clough and Swinden systems the following points deserve notice. The acid condition of these mountain streams in flood time is not remarkable in view of the peaty nature of portions of the gathering ground and the possibility on certain areas of the rain stagnating in the peat. Experiments show that peaty water (whether natural or artificially prepared) is usually acid and possessed of plumbo-solvent ability. The practically neutral condition of samples of Cant Clough and Swindon Beck obtained at a later date, and under ordinary conditions of rainfall, is to be accounted for by the comparative absence of surface peaty water and the relatively large amount present of spring water or of water altered in character by its passage through or over rocky soil.

"*Springs*" *Supply.*—This water, as might have been expected, was found to be neutral and free from plumbo-solvent ability. Hillside springs on moorland gathering grounds appear to be always neutral and free from action on lead. In some cases, indeed, a slight acidity has been detected, which disappears on exposure of the water to the air, and is probably due to the presence of minute traces of carbonic acid. From experiment No. 9 of the accompanying table of chemical results it will be noted that this spring water was not only neutral, but possessed a considerable acid neutralising ability.

Heckenhurst Reservoir was neutral and free from plumbo-solvent ability. It is probable that even if Cant Clough and Swinden Reservoirs supplied acid water to this reservoir it would be neutralised by the water from "springs" supply. Spring water is not only neutral but always appears to have as well some acid neutralising ability.

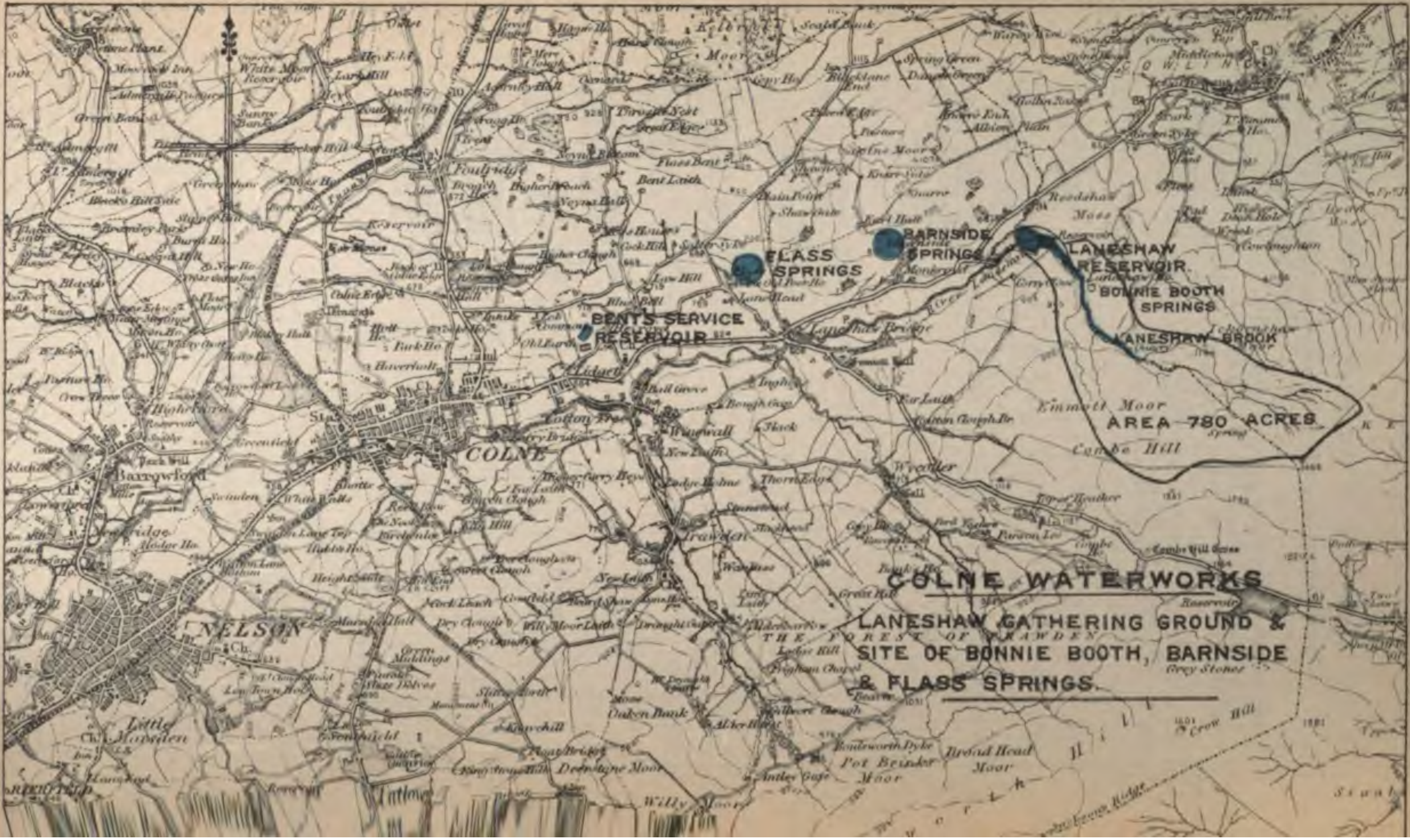
## BURNLEY CORPORATION WATERWORKS.

### TABLE 9.—*Chemical and Bacteriological Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 cc. | | | | | | Number of Micro-Organisms in 1 c.c. of the Water |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. | |
| 1 | "Spring" water. March 27th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | — |
| 2 | "Outlet" from Swinden Reservoir No. 1. March 27th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | 960 |
| 3 | Water from Heckenhurst Reservoir, containing mixture of spring water and water from Cant Clough and Swinden Reservoirs. March 27th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 | — |
| 4 | Cant Clough Reservoir water. March 27th, 1896. | Trace acid | Trace acid | Traces. | | | | | | 225 |
| 5 | Swinden Brook during flood. March 27th, 1896. | Distinctly acid. | 0·42 | 0·2 | 0·4 | 0·5 | 0·5 | 0·5 | 0·42 | 414 |
| 6 | Swinden Brook during dry weather. April 2nd, 1896. | Trace acid | Trace acid | Traces. | | | | | | |
| 7 | Cant Clough Beck during flood. March 27th, 1896. | Very acid | 0·78 | 1·0 | 1·6 | 1·9 | 1·9 | 1·9 | 1·66 | 960 |
| 8 | Cant Clough Beck during dry weather. April 2nd, 1896. | Trace acid | Trace acid | Traces. | | | | | | |
| 9 | Equal parts of the "spring" water (Experiment No. 1) and of Cant Clough Beck water (Experiment No. 7) mixed together, and kept in an unstoppered bottle for three days, and then tested for acidity and plumbo-solvent ability. | ? Very faint trace acid. | Trace acid | Traces. | | | | | | |

# COLNE WATERWORKS.

*(April 9th 1896)*



## Survey No. 10.

### COLNE WATERWORKS.

### Source of the Water Supply and General Description of the Waterworks.

The supply is obtained from hillside springs and from moorland and springs at Laneshaw.

*Hillside Springs.*—There are two springs known as Flass and Barnside Springs. The water from these springs is piped to Bent's Service Reservoir and is conveyed from thence by a single main to Colne. Bent's Service Reservoir also receives the water from Laneshaw, although this water can be passed directly into consumption.

*Laneshaw System.*—The water from Laneshaw Brook is collected in Laneshaw Reservoir: thence, after filtration through sand and polarite, it joins the water from Bonnie Booth Springs and passes either directly into consumption or is dammed back to raise the level of the water in Bent's Service Reservoir. The water from springs known as Bonnie Booth Springs is piped past Laneshaw Reservoir to join, at a lower level, the filtered water from Laneshaw Reservoir.

A storm watercourse exists in connexion with Laneshaw Brook, and in flood time none of the water is allowed to enter the reservoir.

The following notes on Colne Waterworks are of interest:—

#### *Rainfall.*

Average yearly rainfall on gathering ground, $34\frac{6}{10}$ inches.

#### *Capacity and Top Water Level of Laneshaw Reservoir.*

| — | Capacity. | Top Water Level. |
|---|---|---|
| | Gallons. | Feet. |
| Laneshaw Reservoir - - - - - | 81 millions. | 858 |

#### *Drainage Area.*

Laneshaw drainage area, 779 acres.

Yield of district for drought of 150 days:—
73 million gallons in reservoir for compensation water.
8 " " " for town supply.
8,000,000 gallons ÷ 150 days = 50,000 gallons per day for town.
Yield of springs in dry weather 250,000

Total from Laneshaw - 300,000
Supply from Bent's Reservoir 80,000

Total supply to town - 380,000 gallons.

### *Consumption of Water.*

The consumption of water is estimated at 350,000 gallons per day.

*Daily Rainfall from March 9th to April 9th*, 1896.

| Date. | New Gauge Works A. | Date. | New Gauge Works A. |
|---|---|---|---|
| | Inches. | | Inches. |
| March 9th | — | March 28th | ·030 |
| " 10th | ·006 | " 29th | ·020 |
| " 11th | ·05 | " 30th | — |
| " 12th | — | " 31st | — |
| " 13th | ·037 | | |
| " 14th | — | Totals | $2\frac{34}{100}$ |
| " 15th | ·024 | | |
| " 16th | ·05 | | |
| " 17th | ·04 | April 1st | ·011 |
| " 18th | — | " 2nd | ·09 |
| " 19th | ·011 | " 3rd | — |
| " 20th | ·013 | " 4th | ·03 |
| " 21st | — | " 5th | — |
| " 22nd | — | " 6th | — |
| " 23rd | ·05 | " 7th | — |
| " 24th | ·09 | " 8th | — |
| " 25th | ·030 | " 9th | — |
| " 26th | ·035 | | |
| " 27th | — | Totals | $\frac{13}{100}$ |

### *Notes on the Characters of the Gathering Ground.*

*Flass and Barnside Springs* are hillside springs which yield an abundant and constant source of water. The slopes of the hills on this portion of the gathering ground are covered with rough pasture grass, and the rock underlying the surface soil is sandstone grit.

*Bonnie Booth Springs.*—The water from these springs is received into a closed chamber as soon as it issues from the ground, and is piped directly into the waterworks supply. A similar arrangement exists in connexion with Flass and Barnside Springs. The site of Bonnie Booth Springs is near the entrance of Laneshaw Brook into Laneshaw Reservoir.

*Laneshaw Brook and Laneshaw Reservoir.*—Laneshaw Brook drains a large area of moorland. Towards its source the character of the ground is essentially peaty, but lower down the surface soil is much less peaty and supports the growth of rough pasture grass. The bed of the stream is rocky, and the denudation of the sides of the valleys allows a large quantity of sand and rock to be washed down its course during storms. In addition to the water derived from surface drainage which—especially in its upper reaches—is more or less peaty in character, Laneshaw Brook receives a large quantity of spring water.

The rock underlying the surface soil is sandstone grit.

### *Conditions found to exist on the Gathering Ground on April 9th*, 1896.

Lacmoid was used to test the reaction of the various waters and it is to be noted that when a water gives a neutral reaction with this reagent it will not dissolve lead to any appreciable extent under laboratory conditions of experiment.

The water from Flass, Barnside, and Bonnie Booth Springs was neutral in reaction. Laneshaw Brook was running very low, owing to the prolonged drought, and contained chiefly spring water. It was neutral in reaction, and a sample of water obtained at a later date, and in flood time, was also neutral.

The water in Laneshaw Reservoir was neutral in reaction.

Samples of water were collected for more detailed examination from Flass, Barnside, and Bonnie Booth Springs, and from Laneshaw Reservoir. Later, a sample of flood water was obtained from Laneshaw Brook, and a sample of water from an "ochre" spring on the gathering ground.

Briefly, the examination of these waters showed that they were all neutral and free from plumbo-solvent ability.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

The neutral condition and freedom from action on lead of the spring waters might have been expected. Omitting the consideration of those spring waters, which contain an excess of free carbonic acid, it is a matter of experience that spring waters are neutral and do not act on lead.

It remains only to consider why Laneshaw Brook, which drains moorland, is similarly free from acidity and plumbo-solvent ability. In this connexion the following points are to be noted :—

(1.) The large amount of spring water relative to surface water.

(2.) The character of the soil drained.

It has been already said that the lower reaches of Laneshaw Brook drain land only partially peaty, and covered with rough pasture grass, and that it is only towards its source that peat is abundant, either in superficial extent or in depth.

(3.) The run of the water for a considerable distance on a rocky and sandy bed, subject to constant renewal by denuding agencies.

Lastly (4.), the rain appears to run rapidly off the surface of the ground over most of the gathering ground, although, no doubt, in places exceptional opportunity exists for its stagnation in the soil.

It might have been expected, however, that Laneshaw Brook would be acid in flood time. This does not seem to be the case, since a sample, obtained during storm time, was neutral and free from plumbo-solvent ability.

Possibly at one period of a storm the water may be acid, namely, at its beginning, when the rain washes out the soil water which has lain there for some time previous.

The neutral condition of Laneshaw Reservoir indicates that, at all events, for some months before the day on which it was tested, it must have been supplied with neutral water from Laneshaw Brook.

In conclusion, it is to be noted that the provision of a watercourse to carry off the water from Laneshaw Brook, in storm time, must beneficially affect the quality of the water stored in the reservoir.

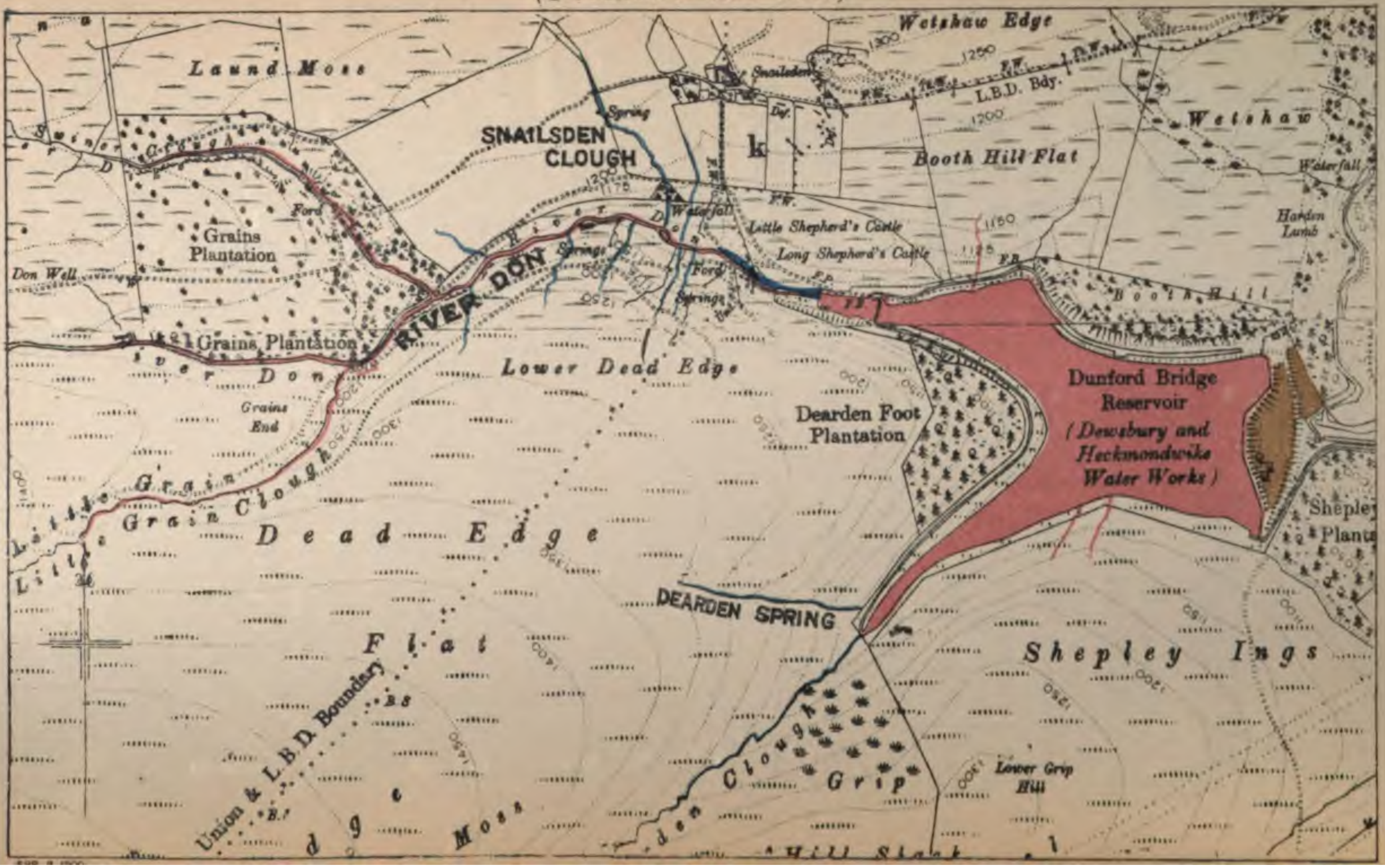
## Colne Waterworks.

### Table 10.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Acidity. | | Action on Lead (results stated as Parts per 100,000). The action on Lead was tested by Upward Filtration through 50 c.c. washed Lead Shot. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Reaction with Lacmoid. | In terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | April 10th, 1896, water from Flass Springs. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 2 | April 10th, 1896, water from Barnside Springs. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 3 | April 10th, 1896, water from Bonnie Booth Springs. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 4 | April 10th, 1896, water from Laneshaw Reservoir. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 5 | April 20th, 1896, water from Laneshaw Brook. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |
| 6 | May 12th, 1896, water from "ochre" spring. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 |

DEWSBURY AND HECKMONDWIKE WATERWORKS.

(November 23rd 1894.)



## Survey No. 11.

### DEWSBURY AND HECKMONDWIKE WATER BOARD.

### Source of the Water Supply and General Description of the Waterworks.

The water supply of the Dewsbury and Heckmondwike Water Board is obtained from moorland gathering ground situate at Dunford Bridge, about 16 miles south-west from Dewsbury.

Dunford Bridge, the chief* storage reservoir, is situated in the valley of the Don, at a height of 1,100 feet above sea level. The main sources of supply to this reservoir may briefly be described as follows:—

Great Grain, Middle Grain, and Little Grain Cloughs unite to form the River Don, which, after receiving the water from Swinehill and Snailsden Cloughs, and numerous smaller feeders, discharges into the reservoir at its north-western extremity.

Dearden Clough and Dearden Spring enter the reservoir at its south-western end.

Besides the above, there are a large number of small feeders which enter the reservoir at various points. These contain chiefly surface drainage water from peat, and during dry weather are for the most part empty.

A watercourse connects Dearden Clough and the River Don, and a large number of small streams, chiefly of the nature of peat drains, are piped into this channel. The water derived from this source, however, is inconsiderable except in storm time.

Another watercourse extends along the north side of the reservoir. It is connected with the River Don at its upper end, and terminates at the reservoir embankment, from which point the water is conveyed by pipes across the Harden Valley to the aqueduct leading to the towns. Several small feeders open into this channel similar in character to those discharging into the western conduit.

The water, after leaving Dunford Bridge Reservoir, is conveyed without filtration to Broadstone Reservoir (on line of aqueduct) and Whittey Reservoir (at end of aqueduct and beginning of piping).

The daily quantity of compensation water which has to be delivered to the River Don is 1,889,285 gallons.

The following notes on the waterworks are of interest:—

### *Rainfall.*

Average yearly rainfall in Dewsbury. †No record.
" " " on the gathering ground, 50·32, 1862 to 1895 inclusive.

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* There are two storage reservoirs—Upper and Lower Windleden—constructed on the Windleden Brook. The level of the Lower Reservoir is such that water can only be used for compensation purposes. The upper can be used for supply as well as for compensation. Two additional reservoirs are being constructed in the Harden Valley at Dunford Bridge, which will increase the storage 137,600,000 gallons. The additional drainage area thus obtained will be 486 acres.

† There are no returns over so long a period at Dewsbury but the comparison for 1895 stands as 44·50 inches at Dunford Bridge, to 25·60 at Staincliffe, near Dewsbury.

### *Capacity, &c., of Dunford Bridge Reservoir.*

| Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|
| Cubic Feet.<br>39,462,197<br>Gallons.<br>245,849,487 | Feet O.D.<br>1,100 | Feet.<br>70 | A. R. P.<br>31 0 5 |

The capacities of all the reservoirs are as follows:—

### *On the Drainage Area at Dunford Bridge.*

| | Gallons. |
|---|---|
| Dunford Bridge Reservoir - - - | 245,849,487 |
| Lower Windleden Reservoir - - - | 82,765,587 |
| Upper Windleden Reservoir - - - | 137,794,740 |
| | 466,409,814 gallon |

### *Reservoirs having no Drainage Areas, but fed by Water taken to them from Dunford Bridge.*

| | Gallons. |
|---|---|
| Broadstone Reservoir (on line of aqueduct) - | 80,822,173 |
| Whittey Reservoir (at end of aqueduct and beginning of piping) - - - | 45,009,767 |
| | 125,831,940 |
| | 466,409,814 |
| Total storage - | 592,241,754 gallons |

### *Consumption of Water.*

859,730,280 gallons for year 1895 for joint board and outlying districts.

### *Drainage Area.*

1,300 acres.

### *Daily Rainfall on the Gathering Ground from October 23rd, 1894, to November 23rd, 1894, inclusive.*

| Date. | Inches. | Date. | Inches. |
|---|---|---|---|
| 1894. | | 1894. | |
| October 23 - - | 0·47 | November 8 - - | 0·60 |
| „ 24 - - - | 1·01 | „ 9 - - | 0·09 |
| „ 25 - - | 0·96 | „ 10 - - | 0·45 |
| „ 26 - - - | 0·79 | „ 11 - - | 0·07 |
| „ 27 - - | 0·17 | „ 12 - - | 0·20 |
| „ 28 - - - | 0·19 | „ 13 - - | 1·10 |
| „ 29 - - | 0·80 | „ 14 - - | 0·09 |
| „ 30 - - - | 0·09 | „ 15 - - | 0·00 |
| „ 31 - - | 0·11 | „ 16 - - | 0·10 |
| November 1 - - | 0·35 | „ 17 - - | 0·02 |
| „ 2 - - | 0·03 | „ 18 - - | 0·00 |
| „ 3 - - | 0·13 | „ 19 - - | 0·05 |
| „ 4 - - | 0·09 | „ 20 - - | 0·15 |
| „ 5 - - | 0·00 | „ 21 - - | 0·00 |
| „ 6 - - | 0·04 | „ 22 - - | 0·03 |
| „ 7 - - | 0·56 | „ 23 - - | 0·00 |

## *Notes on the Characters of the Gathering Ground.*

The gathering ground consists almost entirely of moorland, with a small area of mountain pasture.

The surface soil is peaty, and it may be stated in general terms that peat is abundant superficially and in depth. Its depth* is greatest on the higher and flatter portions of the collecting ground, and least on the lower and more abrupt slopes of the hills.

The geological formation underlying the peat is chiefly Millstone grit, and shales of the carboniferous series. In consequence of their broken character they yield a considerable quantity of spring water.

The vegetation for the most part heather and moss, but there are also areas covered with rough pasture grass.

The slopes of the hills near the reservoir are very abrupt and the drainage from the soil good, but higher up on the collecting ground towards the ultimate source of the water supply the conditions are not so favourable, *e.g.*, the upper reaches of Grain, Little Grain, and Swinehill Cloughs. Here the ground is flatter, and the water does not flow so rapidly off the surface, and there is a tendency for the rain to saturate the peaty soil, and to stagnate, forming peat and moss pools and marshy places.

Most moorland water supplies are deficient in spring water, and rich in surface drainage water. This particular supply is not an exception to the rule, yet it may be said that here the dry-weather flow is fairly good, and that the proportion of spring to surface water is rather above the average.

The larger feeders run on rocky and sandy beds, which are subject to a certain amount of renewal from the constant denudation of the hill-sides.

In conclusion, it is to be noted that the characters of the gathering ground are such that the bulk of the water draining into the supply is derived from the surface drainage of peat.

## *Conditions found to exist on the Gathering Ground on November* 23, 1894.

As is shown in an accompanying table, the rainfall for some little time previous to the above date was below the average and in consequence many of the streams supplying the storage reservoir were dry, or contained very little water.

Lacmoid was used to test the reaction of the various waters, and it is to be noted that—under laboratory conditions of experiment—when a water gives a neutral reaction with this reagent it will not dissolve lead to any appreciable extent, but that when the reaction is acid, then the water is capable of dissolving lead to an extent depending on the amount of the acidity..

Dunford Bridge Reservoir water was tested at various points, and the water was found to be acid in reaction.

On the south side of the reservoir two small streams draining from the peat were found to have a distinctly acid reaction.

Dearden Clough and Dearden Spring were neutral; but it is possible that the former may be acid in storm time, when the proportion of surface water to spring water is increased.

The small streams which under ordinary conditions discharge into the western watercourse and derive their water chiefly from peat drainage, were dried up, and so could not be tested. The same remar [illegible] apply to similar streams discharging into the northern watercour [illegible] One of these, however, contained sufficient water to be tested, and w [illegible] acid in reaction. It is not unlikely that the majority of these strea [illegible] have a similar reaction in storm time.

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* The depth of peat probably varies from 1 to 6 feet.

The River Don, the main feeder to Dunford Bridge Reservoir, was traced upwards for some considerable distance, and numerous tests were made of the reaction of the water in it at various points along its course, as well as the reaction of its chief tributaries. The water from the upper reaches, viz., from Grain, Little Grain, and Swinehill Cloughs was very decidedly acid in reaction but before reaching the reservoir the reaction of the water in the river gradually changed from acid to neutral, as the result, apparently, of receiving neutral water from a number of hillside springs. Altogether eight streams, including Snailsden Clough, were found to be supplying the river with neutral water.

The gradual change of reaction in this moorland stream from an acid to a neutral water was very carefully worked out, and the results are shown in an accompanying map.

Samples of water were collected for more detailed examination from Dunford Bridge Reservoir and from the River Don at a point just above where it discharges into the reservoir. Subsequently further samples of water were obtained from Dunford Bridge Reservoir. The results are given in an accompanying table. The River Don was neutral and free from plumbo-solvent ability. Dunford Bridge Reservoir water (4 samples) was acid, and acted distinctly on lead. All the waters were very " soft."

### *Remarks on the Results of the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

It is to be noted that the conditions found to exist on November 23, 1894, were not normal as regards the rainfall. For some little time previously little or no rain had fallen on the gathering ground, and in consequence the streams contained an undue proportion of spring water and very little surface water. Under these circumstances it is not surprising to find that the reservoir water was acid and the inlet streams to the reservoir neutral. There can be little doubt that many of the streams which were dry on the above date ordinarily contain acid water derived from the drainage of peaty soil. It is possible that Dearden Clough is acid in storm time, and it is in the highest degree probable that the River Don usually contains an acid water. In short, it may be safely assumed that Dunford Bridge Reservoir is supplied with neutral water during the dry-weather flow of its " inlet " streams, and that it is fed with acid water when the conditions are less favourable as regards the rainfall. In the former case the water is chiefly derived from hillside springs, and in the latter case from the drainage of peaty soil. In this connexion the results of the examination of the water of the River Don are of especial interest.

It was found that the water from the higher collecting grounds was very acid. This water is derived from the drainage of land rich in peat. Moreover, the conditions on this portion of the gathering ground are such that the rain tends to stagnate in the peat, forming peat and moss pools and marshy places. Here there is little or no spring water. The gradual neutralisation of the River Don on its way down to the reservoir is easily accounted for. It has been shown that the water from eight streams discharges into the River Don. These streams contained some surface peaty water, but chiefly water from hillside springs. Experiments show that such water is not only neutral, but possessed of some acid neutralising ability. Again, low down near the reservoir the slopes of the hills are abrupt, and the peat is not so abundant superficially or in depth. Lastly, the flow of the water along a rocky and sandy bed had, doubtless, some slight influence in the direction of neutralising the acidity.

It was particularly noted that the neutralisation of the water was *gradual*, and that each neutral stream entering the river slightly diminished the acidity, until at last, and just before reaching the reservoir, the water ceased to contain any traces of acid. It is only natural to believe that in storm time the spring water would be far too small in amount to neutralise the enormous increase in the acid peaty water.

In conclusion it is to be noted that the chemical results are in accordance with the observed characters of the gathering ground.

### DEWSBURY AND HECKMONDWIKE WATERWORKS.

### TABLE 11.—*Chemical Results.*

| Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2Co_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCo_3$ parts per 100,000). | Action on Lead (Results stated as parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| **November 24th, 1894.** Dunford Reservoir water (near "outlet"). | Acid | 0·42 | 2·8 | 0·1 | 0·4 | 0·5 | 0·6 | 0·6 | 0·44 |
| **November 24th, 1894.** Water from the River Don, the main feeder to Dunford Reservoir. The sample of water was collected at a point near the entrance of the river into the reservoir. | Neutral | Neutral | 2·4 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| **January 23rd, 1895.** Dunford Reservoir water (near "outlet"). | Acid | 0·42 | 2·9 | 0·1 | 0·3 | 0·4 | 0·5 | 0·5 | 0·36 |
| **September 6th, 1895.** Dunford Reservoir water (near "outlet"). | Acid | 0·36 | 3·1 | 0·1 | 0·2 | 0·3 | 0·4 | 0·4 | 0·28 |
| **April 2nd, 1896.** Dunford Reservoir water (near "outlet"). | Acid | 0·36 | — | 0·4 | 0·6 | 0·6 | 0·6 | 0·6 | 0·56 |

# Survey No. 12.

## HALIFAX CORPORATION WATERWORKS.

### Source of the Water Supply and General Description of the Waterworks.

The waterworks derive their supply from the Hebble, Luddenden, Widdop, and Greave Valleys.

The *Ogden Reservoir* is situated in the Hebble Valley, and receives the drainage of 1,140 acres, and holds 221,806,000 gallons of water, of which 990,000 are daily discharged down the stream as compensation water. Leaving the reservoir, the conduit for conveying the water to Halifax passes through Mixenden, and finally empties itself into Ramsden Wood Reservoir. From Ramsden Wood the conduit proceeds to the Albert and Victoria Reservoirs for distribution in the Borough.

Ogden Reservoir is supplied with water from Ogden and Skirden Cloughs, and from a catchwater conduit, which is over a mile in length, and collects the water from the south side of the gathering ground.

*The Fly*, the *Upper Dean Head*, and the *Lower Dean Head* Reservoirs are constructed on the Luddenden Brook.

*Fly Reservoir* contains 193,251,000 gallons, has a drainage area of 919 acres, and is situated at a level of 1,350 feet above the sea. Its main source of supply is from a catchwater drain 1¾ miles long.

*The Upper and Lower Dean Head Reservoirs* are constructed lower down the valley, near to Castle Carr. They contain together 122,155,000 gallons, and have a drainage of 525 acres. Lower Dean Head receives its water from Upper Dean Reservoir, which derives its supply chiefly from two mountain streams.

The compensation water amounts to 1,440,000 gallons per day, and is chiefly obtained from Fly Reservoir.

The conduit from these reservoirs passes down the Luddenden Valley, and finally into Ramsden Wood Reservoir, at which point it joins the Ogden system.

The *Widdop Reservoir* is constructed on the Widdop stream, and also receives, by means of a tunnel, the waters of the *Greave Valley*, so that there is one reservoir for the combined drainage of two valleys. The drainage area is 2,223 acres, and the reservoir contains 640,511,000 gallons. The amount of compensation water is 1,620,000 gallons per day. The water from the reservoir is conducted by pipes and tunnel to Shore End Wood, where it joins the Luddenden system.

It will be seen from the foregoing that there are three systems of water supply, namely, the *Ogden system*, the *Fly* and *Dean Head system*, and the *Widdop and Greave system*. The two latter unite at Shore End Wood, and discharge into Ramsden Wood, which reservoir also receives the Ogden water. The water from these three systems, after mixing in Ramsden Wood, is passed through wire gauze in a screen chamber, and then carried in a conduit to the service reservoirs for distribution in the town.

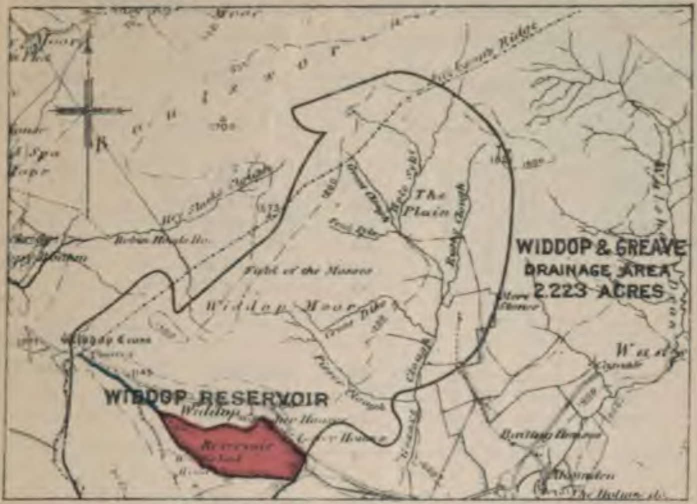
The following notes on Halifax Corporation Waterworks are of interest :—

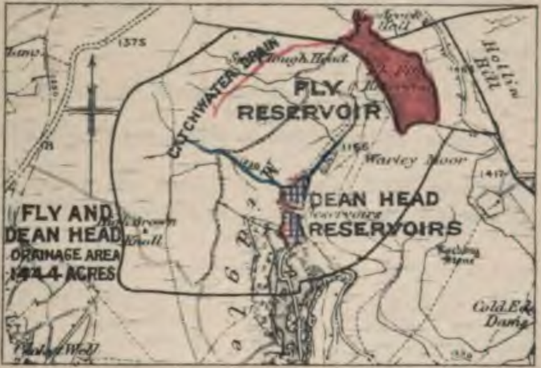
### *Rainfall.*

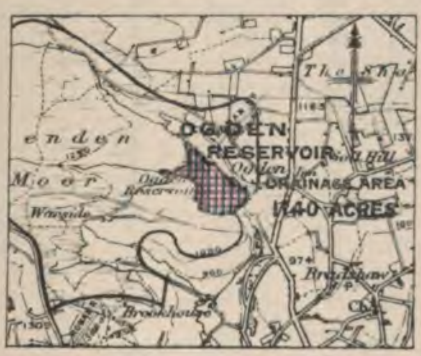
Average yearly rainfall in Halifax :—For 1895, 38·03 ins.; for 1895, 45·62 ins., on the gathering grounds. Taking Warley Moor as a type, the average yearly rainfall at Worley Moor for the last 41 years, ending 1894, was 46·57 ins.

# HALIFAX CORPORATION WATERWORKS.

*(August 29th and 30th 1895)*







E. Weller & Grahams, Ltd Litho. London.

Scale of One Inch to One Statute Mile

0 1 2 3

### *Capacities, &c., of the Chief Reservoirs.*

| Reservoir. | Capacity. | Depth. | Area. | Height above Sea Level. |
|---|---|---|---|---|
| *Storage.* | Gallons. | Feet. | A. R. P. | Feet. |
| Widdop - - - | 640,511,000 | 65 | 93 0 29 | 1,050 |
| Fly - - - | 193,251,000 | 30 | 67 3 30 | 1,350 |
| Upper Dean Head - | 59,143,000 | 54 | 9 2 33 | 1,000 |
| Lower " " - | 63,012,000 | 60 | 9 0 5 | 975 |
| Ogden - - - | 221,806,000 | 66 | 35 0 32 | 980 |
| *Service.* | | | | |
| Ramsden Wood - - | 11,295,000 | 21 | 3 0 27 | 850 |
| Albert - - - | 27,341,000 | 14 | 7 2 25 | 794 |
| Victoria - - - | 12,209,000 | 14 | 2 3 30 | 793 |

### *Drainage Areas.*

| | |
|---|---|
| Ogden - - - - - | 1,140 acres. |
| Fly and Upper and Lower Dean Head | 1,444 " |
| Widdop and Greave - - - | 2,223 " |

### *Consumption of Water for* 1895. *August.*

112,389,624 gallons (exclusive of compensation water).

***Daily rainfall*** during the month of *August* 1895 at Castle Carr Lodge (near Warley Moor), and weekly rainfall during the same month at Warley Moor :—

| 1895. | Castle Carr Lodge. Daily. | Warley Moor. Weekly. | 1895. | Castle Carr Lodge. Daily. | Warley Moor. Weekly. |
|---|---|---|---|---|---|
| | ins. | ins. | | ins. | ins. |
| August 1st | ·04 | — | August 18th | ·00 | — |
| " 2nd | ·09 | — | " 19th | ·00 | ·97 |
| " 3rd | ·18 | — | " 20th | ·00 | — |
| " 4th | ·04 | — | " 21st | ·01 | — |
| " 5th | ·00 | ·39 | " 22nd | ·01 | — |
| " 6th | ·17 | — | " 23rd | ·46 | — |
| " 7th | ·00 | — | " 24th | ·04 | — |
| " 8th | ·09 | — | " 25th | ·23 | — |
| " 9th | ·01 | — | " 26th | ·48 | ·87 |
| " 10th | ·46 | — | " 27th | ·07 | — |
| " 11th | ·66 | — | " 28th | ·16 | — |
| " 12th | ·04 | 1·83 | " 29th | ·04 | — |
| " 13th | ·37 | — | " 30th | ·00 | — |
| " 14th | ·47 | — | " 31st | ·00 | ·98 |
| " 15th | ·02 | — | | 4·15 ins. | 5·04 ins. |
| " 16th | ·01 | — | | | |
| " 17th | ·00 | — | | | |

## *Notes on the Characters of the Gathering Grounds.*

*Ogden System.*—The gathering ground is composed of moorland, and the geological formation is millstone grit. The vegetation is coarse pasture grass on the lower slopes of the hills, and heather on the heights. The surface soil is peaty, but generally speaking peat is not very abundant, either superficially or in depth, except on the higher and flatter portions of the gathering ground, and particularly towards the north-west.

The area drained by the catchwater conduit and Skirden Clough is, on the whole, very free from peat. Ogden Clough, on the other hand, drains land containing much more peat, and this is especially the case towards the source of this, the main feeder to Ogden Reservoir.

The slopes of the hills are precipitous, and the rain falling on the surface is rapidly carried into the storage reservoir.

There are but few places on this gathering ground where the rain saturates the soil, and lies stagnant in peaty or marshy pools.

Skirden and Ogden Cloughs are remarkable in that for the greater portion of their course they are bounded by very precipitous hill slopes, and, in fact, run on rocky and sandy beds at the foot of deep gorges. The soil covering these steep hill sides is very thin, and in many places the underlying rock breaks through to the surface. The denudation is great, especially in storm time, and although no doubt much peat is washed into the waterworks, there is also a large quantity of rock and sand carried from the sides of the hills down the beds of the various streams. The importance of this lies in the fact that in all probability the rock and sand exercise some neutralising action on the peaty water.

On most moorland gathering grounds spring water is small in amount, and surface peaty water very abundant. The Ogden system of water supply is no exception to this rule, but it may be said that the proportion of spring water is above the usual average.

*Fly and Dean Head System.*—For the purposes of description, this system must be sub-divided.

*Fly System.*—The gathering ground is composed of waste moorland, and the amount of peat is simply enormous. In many places the peat beds are over 10 feet in thickness, and the whole of the drainage area is covered with a layer at least 2 feet deep.

There is little or no pasture grass, and the only vegetation appears to be heather and moss.

The drainage area is situated at a height of over 1,500 feet above sea level, and can only be described as a huge flat peat bog.

Underneath the peat are beds of clay, which prevent the water from escaping readily from the peat in a downward direction. This, together with the flatness of the ground, allows the rain to not only saturate the soil, but also to accumulate in hollows, forming peat and bog holes.

There is practically no spring water, the supply being obtained from the slow filtration of the rain through great thicknesses of black peat.

Fortunately this supply is chiefly used for compensation purposes.

*Dean Head System.*—Although this system adjoins the preceding, it differs from it in many important respects.

It is situated on a lower level, there is much less peat, and it resembles the Ogden gathering ground in that the slopes from which the water drains are very steep.

This drainage area, indeed, resembles the Ogden one in many ways; thus the peat beds are thin, the water runs rapidly off the hills into the waterworks, and there is a fair proportion of spring water. Further, there is but little clay underlying the surface soil, the geological formation is millstone grit, and there are but few areas where the rain saturates the soil and stagnates therein.

*Widdop System.*—This system receives its water supply from the drainage of two moorland valleys known as Widdop and Greave.

There is a sparse distribution of peat over the whole of the drainage area, but nowhere is its depth great.

Rough pasture grass as well as heather covers the surface, and beneath the more or less peaty soil is millstone grit.

The slopes of the hills are sufficiently steep to permit of the water being stored in bulk rapidly, and to prevent the rain from accumulating in hollows or depressions.

Although the water derived from surface drainage is great in amount, there is also enough spring water to yield a good dry weather flow.

The Greave Valley gathering ground is perhaps not so satisfactory as the Widdop drainage area.

### *Conditions found to exist on the Gathering Grounds on August 29th and 30th,* 1895.

Owing to the preceding dry weather the conditions were not very favourable, the water in most of the feeders representing the dry weather flow.

Lacmoid was used to test the reaction of the various feeders. This is a very delicate test for acidity in the case of moorland waters.

*Ogden System.*—Ogden Reservoir was tested at various points, and the water was found to have a very faint acid re-action.

The water in the catchwater conduit was neutral, and the water, in Skirden and Ogden Cloughs was practically neutral. The water, however, running in these feeders represented the dry weather flow, and it is quite possible that in storm time, when the amount of surface water would be greatly increased, that different results might be obtained. The faint acidity of the reservoir water points to the probability of the inlet streams being normally, slightly, or occasionally distinctly acid.

*Fly System.*—The water in Fly Reservoir was found to be very acid, and the water in the catchwater drain was also distinctly acid. Owing to the drought the water in the depressions in the peat was in most cases dried up. Many places were found, however, where water, after filtering through the peat, trickled out at a lower level. In all cases this water was very acid.

*Dean Head System.*—The water in Upper and Lower Dean Head Reservoirs was tested at various points and found to be only very slightly acid in reaction. The two inlet streams to Upper Dean Head Reservoir were also tested, and found to be practically neutral, but the flow in them only represented the dry weather flow.

*Widdop System.*—The water in Widdop Reservoir was found to be appreciably acid, but the water in Widdop Stream, which was small in amount owing to the drought, was practically neutral. The water from the Greave Valley contained traces of acid. It is more than probable that the Greave and Widdop waters would be sensibly acid in storm time.

The water in *Ramsden Wood Reservoir* was neutral. As has been already explained, this water is a mixture of the water supplied from the three systems—Ogden, Fly and Dean Head, and Widdop and Greave.

Samples of water were collected for more detailed examination from Lower Dean, Ogden, Fly, and Widdop Reservoirs, and from the Greave Valley conduit, and from the catchwater drain to Fly Reservoir. The results are given in an accompanying table, and they may be described briefly as follows:—

Lower Dean Head Reservoir water was practically neutral, and free from plumbo-solvent ability.

Ogden and Widdop Reservoir waters were slightly acid, and acted appreciably on lead.

The water from the Greave Valley was only very faintly acid, and its action on lead was inconsiderable.

The waters from Fly Reservoir and its catchwater drain were found to be exceedingly acid, and to have a strong plumbo-solvent ability.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Grounds.*

It is to be noted that the characters of the gathering grounds of the Ogden, Dean Head, Widdop, and Greave systems were shown to be comparable in many respects, *e.g.*, as regards the comparative scarcity of peat, &c., &c. So also the chemical examination of these waters showed that they were very similar in certain important respects, *e.g.*, as regards the slight amount of acidity.

The Fly system, however, differed materially from the above in the characters of its drainage area. Thus it was shown that the amount of peat on the gathering ground was very great, and the chemical results showed that the water was extremely acid.

It appears, then, that the chemical results are in accordance with the observed characters of the gathering grounds; and it seems as if the greater or less amount of peaty water accounted for the greater or less acidity of the various waters.

Passing briefly in review the various systems, the following points are worthy of notice.

*Ogden System.*—The acidity of the reservoir water is readily accounted for by supposing that Ogden and Skirdew Cloughs supply it with acid peaty water in storm time. It is the rule to find a mountain stream neutral during its dry weather flow and acid during storm time. That the reservoir was not more acid is to be accounted for by certain redeeming features on this moorland drainage area. These have been already alluded to, namely, the precipitous slopes of the hills, the shallowness of the peat beds, the abrupt flow of the feeders along rocky and sandy beds subject to constant renewal by denuding agencies, the presence of spring water, &c., &c.

The *Dean Head* and the *Widdop and Greave systems* resemble the above in most particulars. The Widdop and Greave system is not quite so satisfactory, however, as the Dean Head, and the reason seems to be that there is more surface peaty water and less spring water in the former system of water supply.

*Fly System.*—The extremely acid condition of the reservoir water and of the catchwater drain is only to be expected from the characters of the drainage area, if it is assumed that peat is the cause of the acidity of moorland waters. For it has been shown that peat is very abundant superficially and in depth, and that the drainage from the peat is very slow. Moreover, the redeeming features which have been alluded to in connexion with the Ogden system are here absent to a large extent.

In conclusion, it is important to note that the mixed water from these various systems in Ramsden Wood Reservoir was neutral.

## HALIFAX CORPORATION WATERWORKS.

### TABLE 12.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Hardness ($CaCO_3$ Parts per 100,000). | Reaction with Lacmoid. | Acidity in terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | Lower Dean Head Reservoir water at "outlet" Halifax Corporation Waterworks. August 30th, 1895. | 4·2 | ? Trace acid | ? Trace acid. | ? Traces. | | | | | |
| 2 | Ogden Reservoir water at "outlet" Halifax Corporation Waterworks. August 30th, 1895. | 4·5 | Faintly acid. | Faintly acid. | Traces. | | | | | |
| 3 | Fly Reservoir water at "outlet" Halifax Corporation Waterworks. August 30th, 1895. | 5·6 | Very acid | 0·78 | 1·0 | 1·4 | 1·6 | 1·8 | 1·8 | 1·52 |
| 4 | Catchwater drain at point of entrance to Fly Reservoir Halifax Corporation Waterworks. August 30th, 1895. | 7·1 | Very acid | 0·96 | 0·5 | 1·5 | 2·0 | 2·0 | 2·5 | 1·70 |
| 5 | Widdop Reservoir water at "outlet" Halifax Corporation Waterworks. August 30th, 1895. | 2·9 | Faintly acid. | 0·30 | 0·1 | 0·2 | 0·3 | 0·3 | 0·3 | 0·24 |
| 6 | Conduit from Greave Valley water, taken from near point of entrance to Widdop Reservoir, Halifax Corporation Waterworks. August 30th, 1895. | 3·2 | Faintly acid. | 0·24 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 | 0·10 |

## Survey No. 13.

### HUDDERSFIELD CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The water supply of the Huddersfield Corporation is derived from gathering grounds lying at a distance of 3 to 7 miles south-west of Huddersfield.

There are three separate sources of supply, viz.:—Longwood, Wessenden, and Blackmoorfoot. The two former derive their water chiefly from hillside springs, and will not be described further. The latter, Blackmoorfoot supply, is wholly from moorland, and calls for a special description.

The *Blackmoorfoot Reservoir* is situate on the south-west side of Huddersfield, at a distance of 4 miles, and at an elevation of 831 feet above sea level. The water from the gathering ground is conveyed into the reservoir by means of catchwater conduits constructed along the contours of the Pennine range of hills for a distance of 5½ miles. There are two embankments to the reservoir. The larger embankment is that on the north side, being 850 yards long, 400 feet wide at its base, and 70 feet high. The southern embankment is 500 yards long, 240 feet wide at its base, and 40 feet high. The main which carries the water from this reservoir to Huddersfield is laid from the north tunnel entrance. It is connected with the Longwood Reservoir main near Longwood Station. The water from this main discharges into the Snodley Service Reservoir at West Hill, which is situated at a height of 500 feet above sea level, and is constructed to hold 1,250,000 gallons. From this service reservoir, water is distributed through the town, and is also taken forward along the Leeds road for the supply of Mirfield and Ravensthorpe. The main from the south tunnel entrance at Blackmoorfoot conveys the water to nine villages, and also to a portion of Huddersfield.

There are sluices in connexion with the catchwater conduits to turn storm water to compensation. When the reservoir is low, however, it becomes necessary to utilise some, at all events, of the storm water.

The following notes on Huddersfield Corporation Waterworks are of interest:—

*Rainfall.*

| | Inches. |
|---|---|
| *Average yearly rainfall at Blackmoorfoot Reservoir* - | 40 |
| " " " *on the gathering ground* - | 46 |

*Capacity, &c. of Blackmoorfoot Reservoir.*

| Capacity. | Height above Sea Level. | Depth. | Area. |
|---|---|---|---|
| | Feet. | Ft. in. | A. R. P. |
| 700,000,000 gallons - | 831 | 48 6 | 101 2 35 |

The available supply of water from Blackmoorfoot Reservoir for the town and neighbourhood is calculated at 3 million gallons per day, exclusive of compensation water, which is given out daily during 12 hours of every lawful working day at 841,680 gallons.

[illegible] in amount, and so turbid that its course was clearly outlined for a considerable distance in the body of water in the reservoir.

Blackmoorfoot Reservoir was tested at various points, and the water was found to be very acid.

The water in Brow Grain Clough and in the catchwater conduits was very acid, and the water in the smaller streams supplying the conduits was, when tested, found to have a similar reaction.

Owing to the severity of the storm, observations were difficult, but so far as could be seen the vast bulk of water entering the waterworks was derived from the drainage of very peaty soil.

It was found impossible to visit the other gathering grounds, which mattered the less as the Blackmoorfoot supply is the only moorland one, the other sources of supply to Huddersfield being chiefly from hillside springs.

Samples of water were obtained for more detailed examination from the catchwater conduit at its entrance to the reservoir, and from Blackmoorfoot Reservoir near the outlet. Subsequently samples of water were obtained from Upper Longwood Reservoir, as representing the spring water supply to Huddersfield, and from Blackmoorfoot Reservoir and its catchwater at a time when the rainfall was not excessive, to serve as a comparison with the original samples.

The results are given in an accompanying table.

It is to be noted that on July 25, 1895, the reservoir water was not nearly so acid, or possessed of so great an action on lead as the water from the catchwater. On April 1, 1896, the conditions were reversed. The waters were harder than is usually found in moorland supplies. Longwood Reservoir water was neutral, and free from plumbo-solvent ability.

As regards the waters which were tested for their reaction on the gathering ground, but which were not submitted to a more detailed examination, it is to be noted that when a water gives an acid reaction with lacmoid, it will dissolve lead under laboratory conditions of experiment.

### *Remarks on the Results of the Chemical Examination of the Waters in reference to the Observed Characters of the Gathering Ground.*

Owing to the heavy storm which broke over the gathering ground on July 25, 1895, after a period of drought, the catchwater conduits contained an enormous amount of very turbid and peaty water. As might have been anticipated, this water was found to be very acid, and it really represented what may conveniently be called the "first washings" of the peat. A sample obtained at a later date and during the dry-weather flow, was very much less acid. Although the foul water entering the waterworks on July 25, 1895, does not represent the normal state of things, yet its quality on that occasion was so bad as to be capable of contaminating a very large body of water. Hence it is not surprising to find that both the reservoir samples of water were distinctly acid. Moreover, it is to be noted that even during the dry-weather flow the catchwater conduit was supplying the reservoir with acid water It appears that Blackmoorfoot Reservoir normally contains a water that is acid and acts on lead, and the reason lies in the characters of the watershed. It has been shown that the gathering ground is very rich in peat, that spring water is not abundant, and, generally, that the conditions are such that the bulk of water entering the waterworks is necessarily contaminated with peat.

In conclusion, it is to be noted that the chemical results are quite in keeping with the observed characters of the gathering ground.

## HUDDERSFIELD CORPORATION WATERWORKS.

### TABLE 13.—*Chemical Results.*

| Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ Parts per 100,000). | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average |
| uly 29th, 1895. Blackmoorfoot Reservoir (near "outlet"). | Acid | 0·38 | 7·0 | 0·2 | 0·3 | 0·4 | 0·5 | 0·5 | 0·38 |
| uly 26th, 1895. Catchwater conduit water at point of entrance to Blackmoorfoot Reservoir, storm water. | Acid | 0·84 | 7·0 | 0·6 | 1·2 | 1·4 | 1·4 | 1·4 | 1·20 |
| gust 15th, 1895. Upper Longwood, reservoir water. | Neutral | Neutral | 8·7 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| ril 1st, 1896. Blackmoorfoot Reservoir (near "outlet"). | Acid | 0·66 | — | 0·4 | 0·6 | 0·8 | 0·8 | 0·8 | 0·68 |
| ril 1st, 1896. Catchwater onduit water at point of ntrance to Blackmoorfoot eservoir. Dry weather flow. | Acid | 0·42 | — | 0·2 | 0·4 | 0·5 | 0·5 | 0·5 | 0·42 |

## Survey No. 14.

## KEIGHLEY CORPORATION WATERWORKS.

### SOURCE OF WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The water supply of the Keighley Corporation is derived partly from springs known as the Janet's Well, Park Wood, and Castle Hill Springs, all situate within the borough, and partly from the Water-sheddels gathering grounds on the Stanbury and Trawden Moors, situate at a distance of 7 miles west of Keighley. The Water-sheddels supply will be the only one described here.

*Water-sheddels Gathering Ground.*—This is a moorland gathering ground, and the water draining from it constitutes the main source of supply to Keighley. The water is stored in a reservoir known as Water-sheddels, and, after filtration, is carried to the service reservoirs for distribution in the borough. More in detail, the arrangements for the collection of water are as follows:—Water-sheddels Reservoir is situated at a height of 1,100 feet above sea level, and is supplied with water from the following sources:—

(1.) Dean Clough Conduit, which extends for a distance of 1⅓ miles, and collects the water from a large area of moorland known as Oakworth Moors, opens at Water-sheddels into a conduit ("North Conduit"), which is carried along the north side of the reservior.

(2.) Ponden Kirk Conduit extends for a distance of 1½ miles, and gathers the water draining from Stanbury Moor. It opens into the conduit which runs along the south side of the reservoir ("Ark Hill Conduit").

The above constitute the chief sources of supply to the reservoir. North Conduit receives, as well as the Dean Clough water, a small amount of water from Great Moss, from a stream draining moorland near the north-west angle of Water-sheddels. The south or Ark Hill Conduit receives, besides the Ponden Kirk water, a considerable amount of water from a number of feeders which drain moorland on the south side of the reservoir. Three small streams are piped directly into the south side of the reservoir, and some water also gains access to the waterworks from peaty swamps at the north-west and south-west angles of the reservoir. North Conduit and Ark Hill Conduit unite below the reservoir embankment, and their storm and overflow water is carried down the Worth valley into the Ponden Reservoir, which is a mill-owners' reservoir made in lieu of giving daily compensation water.

The water from Water-sheddels Reservoir is filtered through coke, then through filter beds containing ground sandstone, broken sandstone and limestone, and, finally, through beds of polarite. After leaving the filter beds, the water is conveyed into a storage reservoir, from thence it is piped—part to the service reservoirs and part direct for distribution in the borough.

The Corporation own the land immediately bordering the reservoir, and the watershed is free from all sources of pollution.

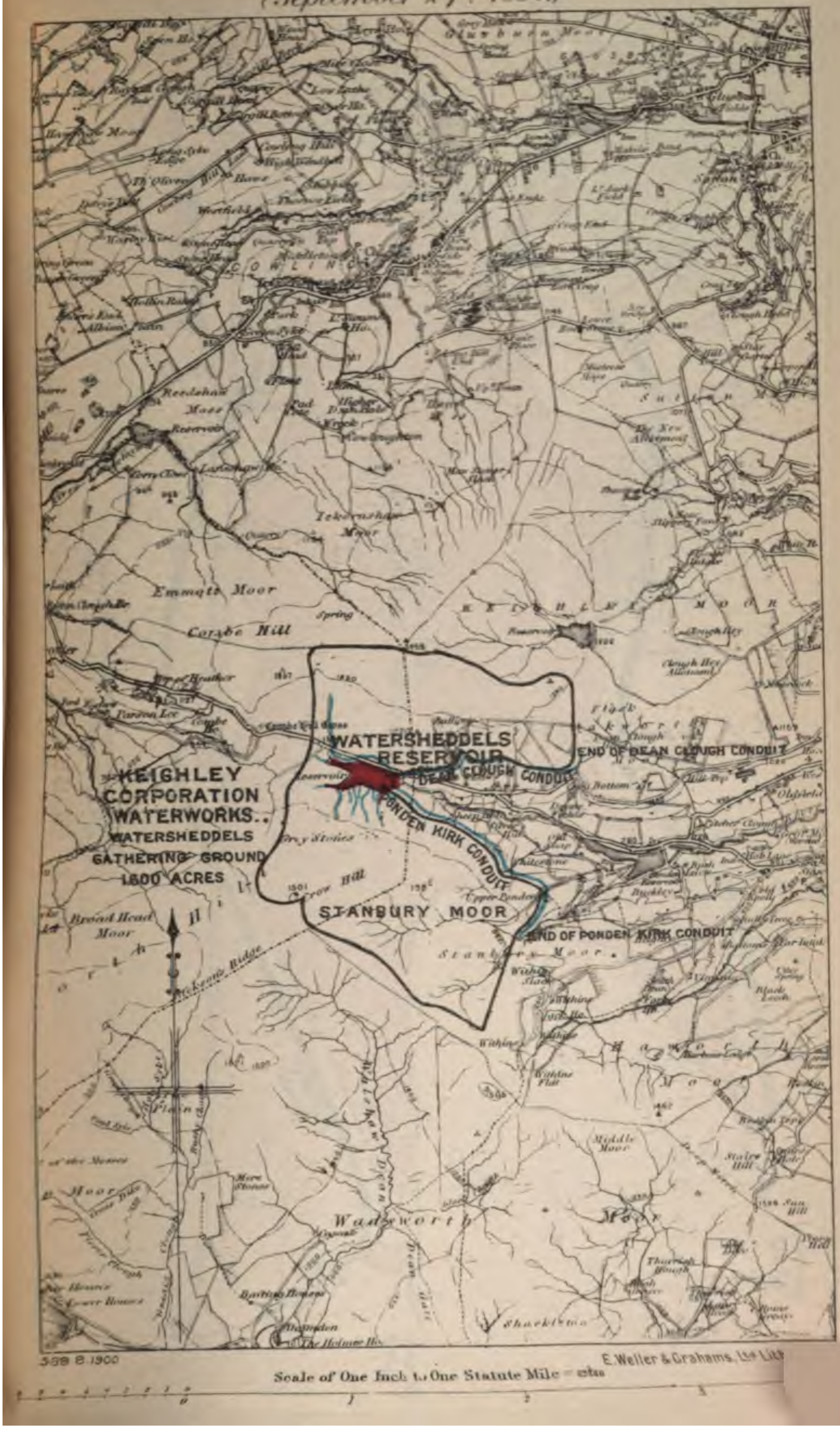
The followings notes on Keighley Corporation Waterworks are of interest:—

### *Rainfall.*

Average yearly rainfall in Keighley, 37·12 inches.
„ „ on the Sheddels gathering ground, 48 inches.

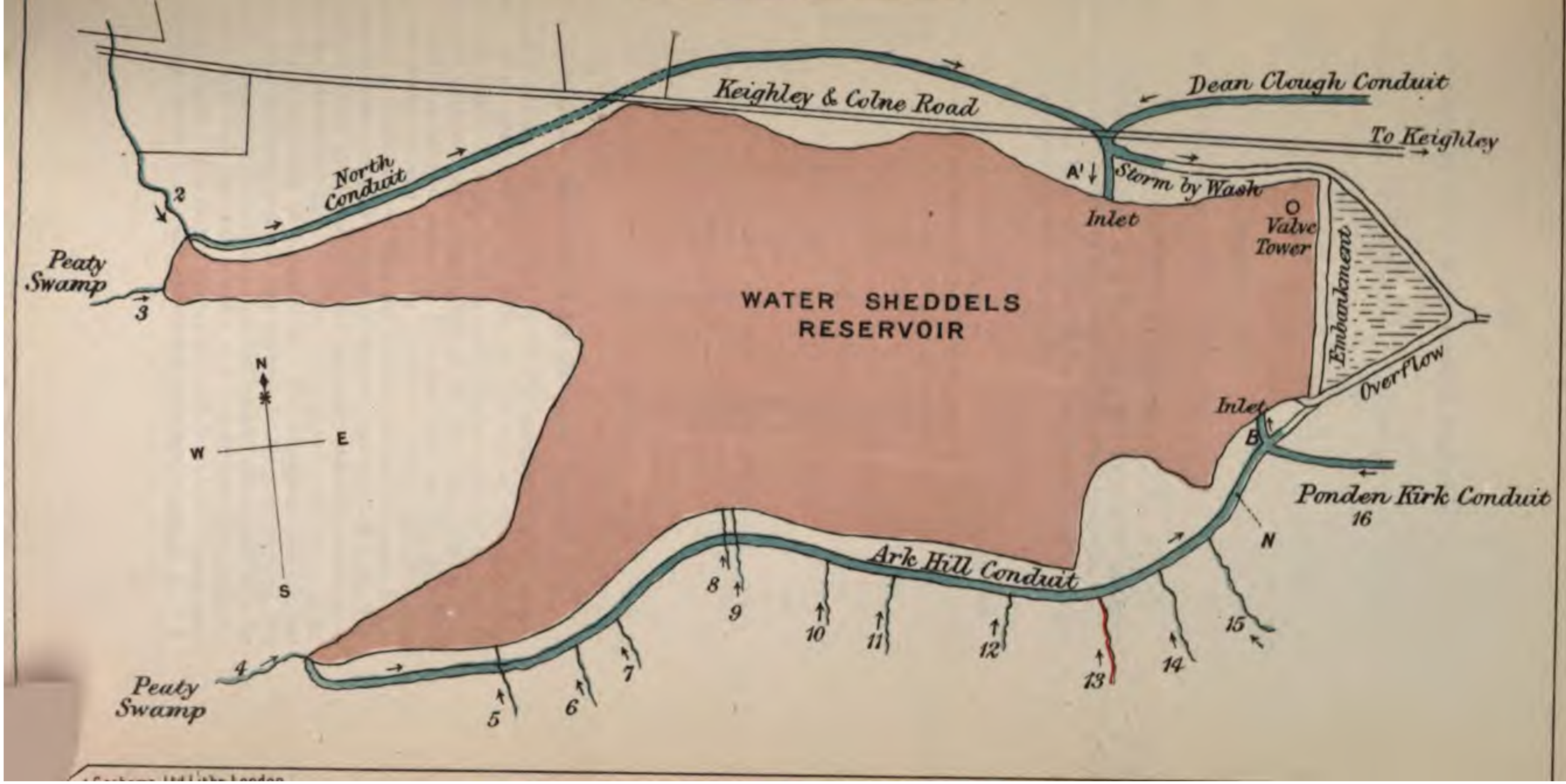
# KEIGHLEY CORPORATION WATERWORKS.

*(September 27th 1894.)*



# KEIGHLEY CORPORATION WATERWORKS.

(*September 27th. 1894.*)



### *Capacity, &c. of Water-sheddels Reservoir.*

| Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|
| Gallons.<br>156,000,000 | Feet.<br>1,100 | Ft. Ins.<br>51 3 | Acres.<br>27 |

### *Drainage Area.*

Water-sheddels gathering ground, 1,600 acres.

### *Consumption of Water.*

About 25 gallons per head per day, including the amount, reckoned at about 3 gallons per head per day, required for trade purposes.

*Daily rainfall* on Water-sheddels Gathering Ground from August 27, 1894, to September 27, 1894, inclusive.

| 1894. | Inches. | 1894. | Inches. |
|---|---|---|---|
| August 27th | ·34 | September 12th | — |
| „ 28th | ·24 | „ 13th | — |
| „ 29th | — | „ 14th | — |
| „ 30th | — | „ 15th | — |
| „ 31st | — | „ 16th | — |
| September 1st | — | „ 17th | — |
| „ 2nd | ·01 | „ 18th | ·03 |
| „ 3rd | ·04 | „ 19th | ·06 |
| „ 4th | — | „ 20th | ·28 |
| „ 5th | ·03 | „ 21st | ·05 |
| „ 6th | ·04 | „ 22nd | — |
| „ 7th | — | „ 23rd | — |
| „ 8th | ·03 | „ 24th | — |
| „ 9th | — | „ 25th | — |
| „ 10th | — | „ 26th | — |
| „ 11th | — | „ 27th | — |

### *Notes on the Characters of the Gathering Ground.*

Water-sheddels gathering ground is wholly moorland. The amount of peat varies considerably on different portions of the collecting ground. In depth it varies from 1 to 6 feet, or even more, and is perhaps most abundant on the south side of the reservoir. The vegetation is chiefly heather and moss, but here and there on the gathering ground are areas covered with the growth of rough pasture grass. The amount of water derived from the surface drainage of peaty soil is very great in storm time. Fortunately the dry weather flow from hill-side springs is fairly good, and this spring water probably counteracts to a considerable extent the evil effects of the peaty water which gains access to the waterworks in storm time. The slopes of the hills on portions of the drainage area are not sufficiently steep to prevent the water from stagnating in peaty swamps and marshy places, and it is in these very places that the peat appears to be most abundant, superficially and in depth. The bed of Water-sheddels Reservoir is peaty, and a considerable amount of peat is washed into the reservoir during floods.

The rock underlying the surface soil is chiefly flatstone or millstone formation.

In conclusion it is to be noted that the characters of the gathering ground are such that the bulk of the water draining into the waterworks is peaty.

### *Conditions found to exist on the Gathering Ground on September 27th, 1894.*

The conditions were not normal as regards the rainfall on September 27th. Owing to the drought most of the water derived from surface drainage was dried up, and the water entering the waterworks represented the dry weather flow. The rainfall from August 27th to September 27th is given in an accompanying table. Lacmoid was used to test the reaction of the various waters, and it is to be noted, in the case of those waters which were not submitted as well to tests as to their action on lead, that when a water gives a neutral reaction with lacmoid it will not dissolve lead to any appreciable extent, but that when it gives an acid reaction with this reagent it posesses plumbo-solvent ability—under laboratory conditions of experiment.

Water-sheddels Reservoir was tested at various points and the water was found to have a distinctly acid reaction. The reservoir water after filtration was neutral. The water in the North, Dean Clough, Ponden Kirk, and Ark Hill Conduits was neutral in each instance. As regards the smaller feeders, some of them were quite dry, and most of them contained only a small amount of water chiefly from hillside springs. For the purposes of description these are numbered on an accompanying map. Briefly stated the results of the tests were as follows: Only one feeder—No. 13—was acid, all the others were neutral, viz, Nos. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15. Of these 6, 8, and 11, contained chiefly ferruginous spring water.

Samples of water were collected for more detailed examination from Water-sheddels Reservoir, No. 13, peaty feeder, and from the filter beds After filtration the water from the reservoir was neutral and had n action on lead. Water-sheddels Reservoir water and the water fro No. 13 peaty feeder were distinctly acid and possessed considerab plumbo-solvent ability. These results are shown in an accompanyi table, which also shows the results of the examination of various wate obtained subsequently. Reference to this table will be made in t following paragraph.

### *Remarks on the Results yielded by the Chemical Examination of t Waters in reference to the Observed Characters of the Gatheri Ground.*

The characters of the Water-sheddels gathering ground are such th it might be expected that the storage reservoir would contain acid wate This was found to be the case, but the question arises as to why t reservoir water should be acid when all—with a single exception—t feeders entering the waterworks were neutral. The explanati appears to lie in the fact that on September 27th, 1894, the strea were nearly dry, and contained chiefly spring water and very litt water derived from the surface drainage of peat. On the 28th Octob 1894, Dr. Scatterty, the medical officer of Keighley, was kind enoug to visit the gathering ground, and to make certain tests at Dr. Houston suggestion, details of which are given below. Prior to the above da heavy rains had fallen on the gathering ground, and in consequence the feeders contained a large amount of peaty water. Dr. Scatterty found the reservoir water acid, and all the feeders (enumerated in the preceding paragraph) acid as well, with the exception of Nos. 6, 8, and 11, which contained chiefly ferruginous spring water. It appears then that Water-sheddels Reservoir is supplied with neutral water during dry weather, when the streams contain chiefly spring water and very little surface water, and with acid water during flood time, when the proportion of surface peaty water to spring water is greatly increased. On November 17th, 1894, various samples were obtained, and they yielded, on examination, the following results: As before, the reservoir water was very acid, and acted decidedly on lead, and the water, after leaving the filter beds was neutral, and free from plumbo-solvent ability. The other samples were very acid, with the exception of the water from the North Conduits, feeders No. 8 and 11, the feeder to the north-west angle of the reservoir, and Ponden Kirk Conduit, which were neutral. Judging from the characters of the gathering ground it is more than probable that the water in Ponden Kirk and Dean Clough Conduits is acid during certain periods of a storm, it may be at the commencement when the streams contain the "first washings" of the peat. Continuing the description of the chemical results, the following points are to be noted: Altogether 14 samples of reservoir water were tested, and although obtained on widely different dates yielded the same results, inasmuch as the water always possessed considerable acidity and plumbo-solvent ability. The reservoir water, after filtration, was in all cases practically neutral, and free from any serious action on lead. It is to be noted that the filtration appreciably "hardened" the water.

As regards the reservoir water the action on lead varied much more than the acidity, and a rise or fall in the acidity did not always correspond with a rise or fall in the plumbo-solvent ability.

At Dr. Houston's suggestion Dr. Scatterty carefully tested the reaction of the water from the main in his house. These tests were made during the early part of the year 1895. About 50 tests were made altogether at first daily, and afterwards weekly. The water was invariably found to have a neutral reaction.

In conclusion it is to be noted that the chemical results correspond very closely with the observed characters of the gathering ground, and they show that water draining from peat is to be associated with acidity and plumbo-solven ability, and water derived from moorland springs is to be regarded as likely to be neutral and free from action on lead.

### KEIGHLEY CORPORATION WATERWORKS.

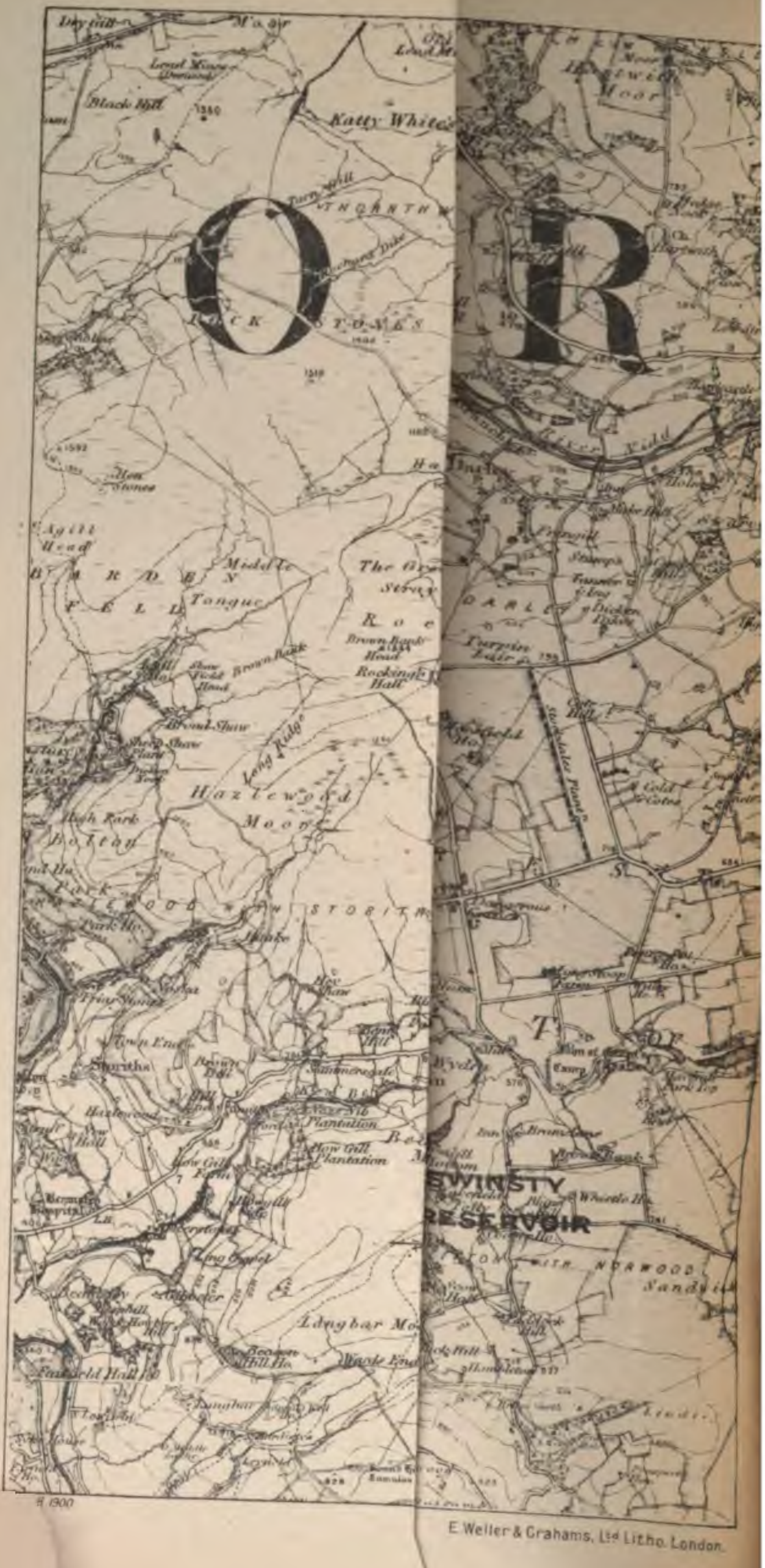
### TABLE 14.—*Chemical Results.*

| Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ Parts per 100,000). | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| pt. 28, 1894. Water-heddels Reservoir ater. | Acid | 0·48 | 2·5 | 0·2 | 0·7 | 0·9 | 1·2 | 1·2 | 0·84 |
| t. 28, 1894. Peaty eder (No. 13) to rk Hill Conduit ater-sheddels Re-rvoir. | Acid | 0·60 | 2·5 | 0·4 | 0·8 | 0·9 | 0·9 | 1·0 | 0·80 |

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2Co_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ Parts per 100,000). | Action on Lead (Results stated as Pa per 100,000). The action on Lead was te by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 min per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Ave |
| 3 | Sept. 28, 1894. Water-sheddels Reservoir water, after filtration. | Neutral | Neutral | 4·7 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | |
| 4 | Nov. 17, 1894. Peaty feeder (No. 13) to Ark Hill Conduit Water-sheddels Reservoir. | Acid | 0·72 | — | — | — | — | — | — | |
| 5 | Nov. 17, 1894. Water entering Water-sheddels Reservoir from conduits on north side. | Neutral | Neutral | — | — | — | — | — | — | |
| 6 | Nov. 17, 1894. Ferruginous spring water (No. 11) to Ark Hill Conduit. Water-sheddels Reservoir. | Neutral | Neutral | — | — | — | — | — | — | |
| 7 | Nov. 17, 1894. Peaty feeder (No. 10) to Ark Hill Conduit. Watersheddels Reservoir. | Acid | 0·60 | — | — | — | — | — | — | |
| 8 | Nov. 17, 1894. Ark Hill Conduit water before mixing with Ponden Kirk Conduit water. | Acid | 0·72 | — | — | — | — | — | — | |
| 9 | Nov. 17, 1894. Ponden Kirk Conduit water (No. 16) to Water-sheddels Reservoir. | Neutral | Neutral | — | — | — | — | — | — | |
| 10 | Nov. 17, 1894. Feeder to N.W. angle of Water-sheddels Reservoir. | Neutral | Neutral | — | — | — | — | — | — | |
| 11 | Nov. 17, 1894. Ferruginous spring water (No. 8) discharging into south side of reservoir. | Neutral | Neutral | — | — | — | — | — | — | |
| 12 | Nov. 17, 1894. Water from peaty swamp (No. 4) S.W. angle of Water-sheddels Reservoir. | Acid | 0·48 | — | — | — | — | — | — | |
| 13 | Nov. 17, 1894. Peaty feeder (No. 5) discharging into south side of Water-sheddels Reservoir. | Acid | 0·72 | — | — | — | — | — | — | |
| 14 | Nov. 17, 1894. Water-sheddels Reservoir water. | Acid | 0·54 | 3·2 | 0·2 | 1·6 | 2·0 | 2·4 | 2·4 | |
| 15 | Nov. 17, 1894. Water-sheddels Reservoir water, after filtration. | Neutral | Neutral | 4·6 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | |
| 16 | Feb. 8, 1895. Water-sheddels Reservoir water. | An accident happened to the bottle, and no tests were made. | | | | | | | | |

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ Parts per 100,000). | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 17 | Feb. 8, 1895. Watersheddels Reservoir water, after filtration. | Neutral | Neutral | 4·3 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 18 | May 17, 1895. Watersheddels Reservoir water. | Acid | 0·54 | 3·64 | 0·7 | 0·9 | 1·0 | 1·0 | 1·1 | 0·94 |
| | May 17, 1895. Watersheddels Reservoir water, after filtration. | Neutral | Neutral | 4·9 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | May 27, 1895. Watersheddels Reservoir water. | Acid | 0·48 | 3·8 | 0·4 | 0·6 | 0·8 | 0·8 | 1·0 | 0·72 |
| | May 27, 1895. Watersheddels Reservoir water, after filtration. | Neutral | Neutral | 4·9 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | June 5, 1895. Watersheddels Reservoir water. | Acid | 0·54 | 3·92 | 0·4 | 0·8 | 0·8 | 1·0 | 1·2 | 0·84 |
| | June 5, 1895. Watersheddels Reservoir water, after filtration. | Neutral | Neutral | 5·46 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | July 9, 1895. Watersheddels Reservoir water. | Acid | 0·48 | 3·92 | 0·4 | 0·6 | 0·6 | 0·8 | 0·8 | 0·64 |
| | July 9, 1895. Watersheddels Reservoir water, after filtration. | ? trace acid | ? trace acid | 4·78 | Faint traces. | | | | | |
| | Aug. 17, 1895. Watersheddels Reservoir water. | Acid | 0·60 | 4·06 | 0·4 | 0·8 | 1·2 | 1·2 | 1·2 | 0·96 |
| | Aug. 17, 1895. Watersheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | 4·48 | Faint traces. | | | | | |
| | Sept. 2, 1895. Watersheddels Reservoir water. | Acid | 0·48 | 3·9 | 0·2 | 0·4 | 0·6 | 0·8 | 0·8 | 0·56 |
| | Sept. 2, 1895. Water sheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | 4·8 | Faint traces. | | | | | |
| | Sept. 9, 1895. Watersheddels Reservoir water. | Acid | 0·60 | 4·0 | 0·4 | 0·8 | 1·0 | 1·0 | 1·2 | 0·88 |
| | Sept. 9, 1895. Watersheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | 4·6 | Faint traces. | | | | | |
| | Sept. 29, 1895. Watersheddels Reservoir water. | Acid | 0·48 | 3·8 | 0·2 | 0·4 | 0·6 | 0·8 | 0·8 | 0·56 |

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness $CaCO_3$ Parts per 100,000). | Action of Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average |
| 33 | Sept. 21, 1895. Watersheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | 6·0 | Faint traces. | | | | | |
| 34 | Oct. 7, 1895. Watersheddels Reservoir water. | Acid | 0·54 | 4·06 | 0·3 | 0·6 | 0·7 | 0·9 | 1·1 | 0·72 |
| 35 | Oct. 7, 1895 Watersheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | 4·76 | Faint traces. | | | | | |
| 36 | Nov. 4, 1895. Watersheddels Reservoir water. | Acid | 0·54 | 4·2 | 0·2 | 0·8 | 1·0 | 1·0 | 1·2 | 0·84 |
| 37 | Nov. 4. 1895. Watersheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | 5·18 | Faint traces. | | | | | |
| 38 | Nov. 25, 1895. Watersheddels Reservoir water. | Acid | 0·54 | — | 0·6 | 1·2 | 1·4 | 1·4 | 1·6 | 1·24 |
| 39 | Nov. 25, 1895. Watersheddels Reservoir water, after filtration. | Faint trace acid. | Faint trace acid. | — | Faint traces. | | | | | |
| 40 | Mar. 16, 1896. Watersheddels Reservoir water. | Acid | 0·60 | — | 0·6 | 1·2 | 1·4 | 1·4 | 1·4 | 1·20 |
| 41 | Mar. 16, 1896. Watersheddels Reservoir water, after filtration. | Trace acid | Trace acid | — | Traces. | | | | | |



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## Survey No. 15.

### LEEDS CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The water supply of the Leeds Corporation is derived from upland collecting grounds in the valley of the River Washburn, a tributary of the River Wharfe, the most distant part of which collecting grounds is situate 22 miles, and the nearest part 9 miles, north-west of Leeds. Before delivery to consumers, this water is filtered through fine river sand. There are two storage reservoirs on the collecting ground. The upper is known as Fewston Reservoir, and is situated at a height of 533 feet above sea level. The main source of supply to this reservoir is from the River Washburn, and it also receives the water from Thackray Beck and White Cragg Stream. The lower, Swinsty, Reservoir, is situate at a height of 449 feet above sea level. It is supplied with water from Fewston Reservoir and from the following streams:—Spink Burn, Taylor's Beck, Woods' Beck, Swinsty Hall Becks No. 1 and No. 2, and Tarn Beck.

The water is conveyed by three 30-inch gravitating mains from the Swinsty embankment down the Washburn valley to Arthington, 8 miles, in the valley of the Wharfe, where engines* capable of pumping 6,000,000 gallons a day are placed; from these engines a fourth main joins the track of the three, proceeding through Lord Harewood's lands and park to a reservoir, 4 miles, in a valley at the village of Eccup; this reservoir is not a collecting one, but is for the storage of water brought by the before-named mains. It is of large capacity (1,300,000,000 gallons), and secures a great amount of purification by the length of time (three months) the water has to remain in it before being used. From this reservoir, the water passes 3½ miles through the Blackmoor Tunnel and pipe lines, by gravitation, to the filter beds at Weetwood. These filter beds are nearly 5½ acres in extent, and are situate on the northern confines of the city.

The following notes on Leeds Corporation Waterworks are of interest:—

### *Rainfall.*

Average yearly rainfall in Leeds:—No record.

" " " on the gathering grounds:—About 42 inches.

*Capacity, &c. of Fewston and Swinsty Reservoirs.*

| Name. | Capacity. | Top Water Level. | Area. | Depth. |
|---|---|---|---|---|
| | Gallons. | Feet. | Acres. | Feet. |
| Fewston - - - | 866,000,000 | 503* | 156 | 47 |
| Swinsty - - | 960,000,000 | 449* | 156 | 55·1 |

* Above sea level.

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* The water pumped here is not from the River Wharfe, but Washburn water brought by an independent pipe line across the Wharfe to the pumping station.

### *Consumption of Water.*

About 15,000,000 gallons per day.

### *Drainage Areas.*

| | |
|---|---|
| Fewston | 13,025 acres. |
| Swinsty | 4,022 „ |

*Daily rainfall on the gathering ground from September 1st, 1895, to October 1st, 1895, inclusive:—*

| 1895. | Inches. | 1895. | Inches. |
|---|---|---|---|
| September 1st | — | September 17th | — |
| „ 2nd | — | „ 18th | — |
| „ 3rd | ·22 | „ 19th | — |
| „ 4th | ·32 | „ 20th | — |
| „ 5th | ·11 | „ 21st | — |
| „ 6th | ·78 | „ 22nd | — |
| „ 7th | — | „ 23rd | ·05 |
| „ 8th | — | „ 24th | — |
| „ 9th | — | „ 25th | — |
| „ 10th | ·38 | „ 26th | — |
| „ 11th | ·18 | „ 27th | — |
| „ 12th | — | „ 28th | ·01 |
| „ 13th | — | „ 29th | — |
| „ 14th | — | „ 30th | ·01 |
| „ 15th | — | October 1st | ·33 |
| „ 16th | — | | |

### *Notes on the Characters of the Gathering Ground.*

The Fewston and Swinsty gathering ground consists partly of moorland, and partly of mountain pasture. Although the surface soil is to some extent peaty, yet, speaking generally, peat is not abundant either superficially or in depth. The geological formation is millstone grit (sandstone and flagrock).

There appears to be much less heather, and a more abundant growth of grass on this as compared with most of the other large upland collecting grounds situate in the West Riding. The slopes of the hills are such as to allow the water to drain rapidly into the waterworks, and there are but few areas where the rain can saturate and lie stagnant in the surface soil. As compared with other so-called moorland gathering grounds, this collecting ground yields an abundant supply of spring water, and very little surface peaty water. In consequence, the dry weather flow in the streams is above the average. In conclusion, it is to be noted that the characters of the gathering ground are such that the bulk of the water draining into the waterworks is not derived from the drainage of peat, but from hillside springs, or from the drainage of land where there is little or no peat present.

### *Conditions found to exist on the Gathering Ground on October 1st,* 1895.

The water in Fewston Reservoir was tested at various points, and appeared to contain very faint traces only of acidity. Swinsty Reservoir was practically neutral, and all the streams entering this reservoir had a neutral reaction, viz., Spink Burn, Taylor's Beck, Woods' Beck, Swinsty Hall Becks No. 1 and No. 2, and Tarn Beck.

The River Washburn, the chief source of supply to Fewston Reservoir, was neutral. Thackray Beck was also neutral, and White Cragg Stream contained only faint traces of acid.

Samples of water were collected for special examination from various sources, and the results are given in an accompanying table. Briefly, the examination of these waters gave the following results:—The waters from the Washburn river, Thackray Beck, and Spink Burn were neutral, and free from plumbo-solvent ability. A sample of Leeds main water obtained at a later date gave similar results. Fewston and Swinsty Reservoirs, and White Cragg Stream contained water which was only very faintly acid, and acted only very slightly on lead. The waters were "harder" than is usually found to be the case with moorland water supplies.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the Observed Characters of the Gathering Ground.*

It is to be noted that the storage reservoirs and their supply streams were practically neutral. This result might have been anticipated from the characters of the collecting ground, already described. Thus it has been shown that the slopes of the hills allow of rapid drainage, and that there are apparently no areas where the rain saturated peaty soil, and accumulates in hollows and depressions. Again, the proportion of spring water, as compared with surface water, is far above the amount usually found in the case of moorland water supplies. Lastly, the surface water which does reach the waterworks is only contaminated with peat to a small extent, the reason being that the surface soil over the gathering ground is only partially peaty.

LEEDS CORPORATION WATERWORKS.

*Table* 15.—*Chemical Results.*

| Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ Parts per 100,000.) | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| October 18th, 1894. Sample of Leeds "main" water. | Neutral | Neutral | 5·2 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| October 2nd, 1895. Sample of water from the River Washburn—the main source of supply to Fewston Reservoir. | Neutral | Neutral | 8·54 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| October 2nd, 1895. Sample of water from Fewston Reservoir. | ? Faint trace acid. | ? Faintly trace acid. | 7·40 | ? Faint trace. | | | | | |
| October 2nd, 1895. Sample of water from Thackray Beck, one of the supply streams to Fewston Reservoir. | Neutral | Neutral | 6·86 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| October 2nd, 1895. Sample of water from White Cragg, one of the supply streams to Fewston Reservoir. | ? Faint trace acid. | ? Faint trace acid. | 10·10 | ? Faint trace. | | | | | |
| October 2nd, 1895. Sample of water from Swinsty Reservoir. | ? Very faint trace acid. | ? Very faint trace acid. | 7·56 | ? Very faint traces. | | | | | |
| October 2nd, 1895. Sample of water from Spink Burn, one of "feeders" to Swinsty Reservoir. | Neutral | Neutral | 13·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |

## Survey No. 16.

### MORLEY CORPORATION WATERWORKS.

SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS. (*For map, see Survey No.* 13.)

The water supply is obtained from moorland near Mytholmroyd, about 21 miles from Morley.

There is only one reservoir—*Withen's Clough*—on the gathering ground, and it is supplied with water from the following sources:—

*North Catchwater.*—This catchwater drains a large area, chiefly moorland, on the north side of the reservoir.

On the same side of the reservoir are three streams, the central one of which is known as *Jack Clough.*

*Withen's Clough* enters the reservoir at its upper end, and is the main inlet stream to the reservoir.

On the south side of the reservoir are three streams, known as *Great Rut, Deep Slade, and Fletcher's Dyke,* as well as several smaller streams, which are of the nature of peat drains.

*South Catchwater.*—This catchwater drains a very considerable area of peaty land on the south side of the reservoir.

Of the feeders enumerated above, the South Catchwater and Fletcher's Dyke are the most affected by the washing down of peat in times of storm, when, according to the waterworks' engineer, the water is principally used for compensation purposes.

On the north and south sides of the reservoir are bye-channels, which are continued up to Withen's Clough at the upper end, and pass down the sides of the embankment to unite below in the bed of the same stream. They are designed to carry storm and overflow water to compensation. They can also be used to carry away the whole flow of certain of the inlet streams, when they are turbid and discoloured after a storm.

In connexion with all the principal inlet streams are filter beds of stone and sand, covered with limestone and chalk, and in August 1894, slaked lime was being added to the water in these streams before it was allowed to enter the reservoir.

Prior to August 1894 the water in the reservoir was not "treated," but after that date an effort was made by the waterworks authorities to neutralise the water with slaked lime by means of rafts. A further "treatment" has since been adopted, soda in solution being added to the water in the supply well.

The water from Withen's Clough is at present (1896) delivered to the town of Morley without any filtration.

An enormous amount of peat has been removed from the bed of Withen's Reservoir, but the drainage area is so rich in peat that, notwithstanding precautionary measures to exclude it, large quantities are washed into the reservoir, especially in storm time.

### *The following notes on Morley Corporation Waterworks are of interest.*

*Rainfall.*—Average yearly rainfall in Morley. No records. Average yearly rainfall on the gathering ground. Estimated at 41 inches. N.B.—The waterworks engineer supplies the following note: In estimating the quantity of rainfall available for supply, a considerable reduction was made from the gross quantity flowing off the drainage area to allow for the exclusion of such water as would come down during, and immediately after, floods and heavy rains.

*Capacity, &c. of Withen's Clough Reservoir.*—Capacity, 330,000,000 gallons. Top water level, 960 feet O.D. Depth at outlet, 60 feet. Water area, 65 acres.

*Consumption of Water.*—About 800,000 gallons per day.

*Drainage Area.*—1,200 acres.

### *Daily Rainfall on Gathering Ground from June 10th,* 1894, *to August 24th,* 1894, *inclusive.*

Observations cover the 24 hours previous to 9 o'clock a.m. on the dates given.

| — | June. | July. | August. | — | June. | July. | August. |
|---|---|---|---|---|---|---|---|
| 1 | — | — | 0·19 | 17 | — | 0·72 | — |
| 2 | — | — | 0·28 | 18 | 0·15 | 0·95 | 0·25 |
| 3 | — | 0·20 | 0·60 | 19 | 0·07 | 0·11 | — |
| 4 | — | — | 0·42 | 20 | 0·12 | — | 0·62 |
| 5 | — | — | — | 21 | — | 0·14 | — |
| 6 | — | — | 0·21 | 22 | — | — | — |
| 7 | — | 0·21 | 0·11 | 23 | — | 0·19 | — |
| 8 | — | — | 0·25 | 24 | — | 0·08 | 0·20 |
| 9 | — | 0·10 | 0·66 | 25 | 0·14 | 0·29 | — |
| 10 | — | 0·06 | 0·05 | 26 | — | 1·00 | — |
| 11 | — | 0·05 | — | 27 | — | — | 0·51 |
| 12 | 0·62 | — | — | 28 | — | — | 0·14 |
| 13 | — | — | 0·11 | 29 | — | — | — |
| 14 | — | 0·15 | 0·06 | 30 | — | — | — |
| 15 | — | — | 0·81 | 31 | — | — | |
| 16 | 0·31 | 0·56 | 0·40 | | | | |

### *Notes on the Characters of the Gathering Ground.*

The gathering ground is principally composed of waste moorland, and about 150 acres are cultivated land, meadow and pasture. Peat is far more abundant on the south than on the north side of the reservoir. Underneath the peat clay is usually to be found, and the permanent measures are sandstone rock, grit, and shale. The beds of peat vary in thickness, and are usually 2 to 6 feet in depth. The vegetation consists chiefly of heather and moss, but on the north side of the reservoir rough pasture grass covers a considerable area. The larger streams feeding the reservoir run on rocky beds, and the smaller on clay or peat bottoms.

Although the drainage from the soil is fairly rapid, there are numerous places on the gathering ground where the rain saturates the soil and lies stagnate there, forming peaty, mossy and marshy pools. The clay underlying the peat is partly to blame for this state of things as the water cannot readily escape downwards, and so is forced to travel in a lateral direction.

In conclusion it is to be noted that the characters of the gathering ground are such that the water entering the waterworks in drought is very small, and in flood-time very great. The former water is derived chiefly from hill-side springs, and the latter from the drainage of peat. In intermediate conditions of the rainfall the surface peaty water is still the main source of supply. No doubt arrangements exist for the exclusion of storm water, but as the storage reservoir depends in great measure for its supply, not on the dry weather flow, but on surface drainage during and after heavy rains, the bulk of the water used for waterworks purposes must be of a peaty nature.

### *Conditions found to exist on the Gathering Ground on July* 10*th*, 1894, *and on August* 24*th*, 1894.

On July 10th the amount of water entering the reservoir was very small indeed.

The water in the reservoir was tested at various points and was found to be acid in re-action.

The water in Withen's brook, the main inlet stream to the reservoir, was neutral. The feeders on the south side of the reservoir were all acid. On the north side Jack Clough stream and the North Catchwater contained acid water, the rest of the feeders contained neutral water.

Most of the feeders just above their entrance to the reservoir have rough filters of limestone and chalk. In these cases the water, even if distinctly acid before, was found to be invariably neutral after passing through the filters. As however the feeders on July 10, 1894 were running nearly dry this fact has a limited significance.

At this date "treatment" of the water with slaked lime was not in operation.

On August 24th the "feeders" to the reservoir contained plenty of water and the conditions represented fairly well the normal as regards the quality of the water entering the waterworks.

Between July 10 and August 24 and about three weeks before the latter date "treatment" of the water was commenced; "slaked" lime being added to the reservoir water by means of rafts and to certain of the feeders by the use of troughs in which a concentrated mixture of lime and water was made, the lime water being allowed to mix with the water entering the reservoir.

Withen's reservoir was tested at various points and found to be still acid. Withen's brook which was neutral on July 10, *i.e.*, during the dry weather flow, was distinctly acid on August 24.

The water in the North and South Catchwater was very acid and the only neutral water entering the reservoir was from two small streams on the north bank, which contained spring water and water from the drainage of soil almost destitute of peat.

Jack Clough, Great Rut, Deep Slade, and Fletcher's Dyke streams were all acid—particularly the two latter. Two small peat drains situated the one between the South Catchwater and Fletcher's Dyke and the other between Fletcher's Dyke and Deep Slade contained very acid water.

As regards the limestone and chalk filters, these failed in every case to neutralise the water, and the blocks of limestone and chalk were thickly coated with vegetable matter, so that it was unlikely that they could act beneficially on the water.

The treatment with slaked lime was more successful, and, in certain cases, completely neutralised the water in the streams. As has been already shown, however, the reservoir water was still acid.

Various samples of water were collected for more detailed examination, and the results are given in an accompanying table, which contains also the results of the examination of the water as supplied to Morley on different dates. Briefly, the results may be described as follows:—

*Morley Main Water* (three samples) was acid, and acted distinctly on lead on August 17, 1894. On November 3, 1894, the water (probably owing to the continued use of lime) was practically neutral, and free from plumbo-solvent ability. On February 6, 1895, the water was more acid, and acted more decidedly on lead than the sample obtained on August 17, 1894.

*Withen's Reservoir* water, on August 25, 1894, was acid, and had an appreciable action on lead.

*Jack Clough and Withen's Brook*, examined on the same date, were found to possess a nearly similar acidity and action on lead, the quality of the water being not so good as the reservoir water.

*Fletcher's Dyke* (August 25, 1894) was exceedingly acid, and acted most powerfully on lead.

The *North and South Catchwater* and *Deep Slade Stream* (August 25, 1894) were also extremely acid.

*Great Rut Stream* (August 25, 1894) was distinctly acid, but not to the same extent as the above.

So far as could be ascertained by personal observation and by inquiry, Fletcher's Dyke, Deep Slade, and the North and South Catchwaters drained land exceptionally rich in peat, and land where the rainwater saturated the soil, and accumulated and lay stagnant in peaty, boggy, and marshy places. The same remarks apply, although to a much smaller extent, to Withen's Clough, Great Rut Stream and Jack Clough. These three streams, and particularly Withen's Clough, contain some spring water which, during a period of drought, when the surface water is nearly dried up, may have the effect of neutralising the water before it enters the waterworks.

### *Remarks on the results yielded by the Chemical Examination of the Water in reference to the observed character of the Gathering Ground.*

It is to be noted that the chemical results are in keeping with the observed characters of the gathering ground.

The acidity of Within's Reservoir is easily accounted for since it has been shown that even in dry weather many of its "feeders" contain acid water and that in storm time the great bulk of the water entering the waterworks is markedly acid.

The chemical results taken in conjunction with the observed characters of the gathering ground point not only to the association of acidity with water drainage from peaty soil, but also to a certain parallelism between the amount of the acidity and the degree of contamination of the water with peat.

It was observed as a result of a general inspection of the gathering ground that certain wide areas were very rich in peat, and that other areas were poor in this respect. The chemical results showed that the former yielded a very acid water, and the latter a neutral or only slightly acid water. Compare the south with the north side of the storage reservoir in this connexion.

Again it was noted as a result of a closer inspection of the gathering ground that smaller areas existed where the peat was exceptionally deep and the drainage from it very slow, and where the rain not only saturated the soil but lay stagnating in peaty pools.

Such areas yielded a water peculiarly acid, *e.g.*, Fletcher's Dyke.

In conclusion it may be stated in broad terms that if the "feeders" were arranged in order according to the amount of their acidity, and the areas drained by them according to the amount of peat observed to be present, the parallelism existing between the amount of the acidity and the degree of contamination with peaty water would be clearly established.

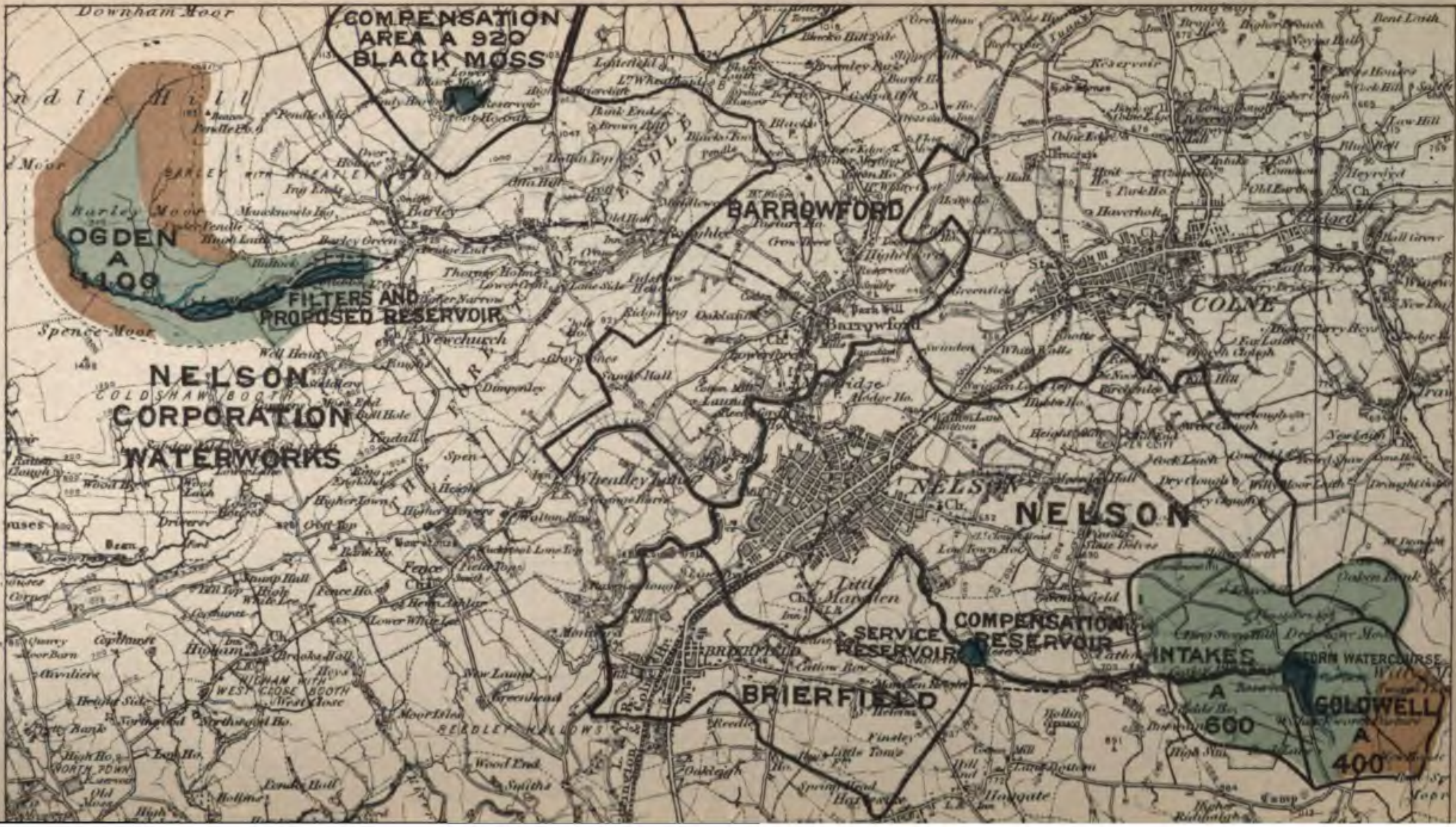
## MORLEY WATERWORKS

*Table* 16.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Hardness ($CaCo_3$ Pts. per 100,000). | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Action on Lead (Results stated as Par per 100,000). The action on Lead was te by upward filtration through 50 c.c. was Lead Shot at the rate of 3 mins. per 50 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Av |
| 1 | August 17th, 1894. Morley main water. | — | Acid | 0·42 | 0·0 | 0·1 | 0·4 | 0·6 | 0·7 | ( |
| 2 | November 3rd, 1894. Morley main water. | 5·7 | ? Trace acid. | Traces. | | | ? Trace acid. | | | |
| 3 | February 6th, 1895. Morley main water. | 5·0 | Acid | 0·60 | 0·5 | 0·5 | 0·5 | 0·6 | 0·6 | ( |
| 4 | August 25th, 1894. Withen's Reservoir water at Mytholmroyd. Morley waterworks. | 4·6 | Acid | 0·30 | 0·0 | 0·1 | 0·2 | 0·2 | 0·2 | 0 |
| 5 | August 25th, 1894. Jack Clough water, one of peat feeders to Withen's Reservoir. | — | Acid | 0·42 | 0·0 | 0·2 | 0·4 | 0·5 | 0·6 | 0 |
| 6 | August 25th, 1894. Withen's brook, main "inlet" to Withen's Reservoir. | — | Acid | 0·42 | 0·0 | 0·2 | 0·5 | 0·6 | 0·7 | 0 |
| 7 | August 25th, 1894. Fletcher's Dyke water, one of peat feeders to Withen's Reservoir. | — | Acid | 1·70 | 3·0 | 6·0 | 6·0 | 6·0 | 7·0 | 5 |
| 8 | August 25th, 1894 North Catchwater at point of entrance into Withen's Reservoir. | — | Acid | 0·96 | — | — | — | — | — | . |
| 9 | August 25th, 1894. Great Rut stream, one of peat feeders to Withen's Reservoir. | — | Acid | 0·48 | — | — | — | — | — | . |
| 10 | August 25th, 1894. Deep Slade stream, one of peat feeders to Withen's Reservoir. | — | Acid | 1·10 | — | — | — | — | — | . |
| 11 | August 25th, 1894. South Catchwater, at point of entrance into Withen's Reservoir. | — | Acid | 1·40 | — | — | — | — | — | . |

# NELSON CORPORATION WATERWORKS.

*(April 2nd 1896)*



## Survey No. 17.

### NELSON CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from two moorland gathering grounds above Coldwell and Ogden Springs, about four and four and a half miles respectively from Nelson.

*Coldwell System.*—Coldwell Reservoir receives its supply from a number of small moorland streams which—under ordinary conditions of rainfall—contain chiefly spring water. In the bed of the reservoir there are a number of springs which yield an abundant supply of water. A storm watercourse runs along one side of the reservoir, and all the streams which discharge ordinarily into the reservoir may be turned down this watercourse. This arrangement allows of the exclusion of storm water from the water supply. The water from Coldwell is not filtered. It is conveyed through an iron pipe direct to "Wades" House Service Reservoir. From this it goes to Nelson, being connected with the main from Ogden in the centre of the town, so that Ogden water can, and does under certain conditions, reach the Service Reservoir.

*Ogden System.*—There is no reservoir, except for compensation purposes, in connexion with this system of water supply.

The water is taken directly from a moorland stream known as Ogden water, and led on to two filter beds (sand and gravel).

After filtration the water is carried by an iron main over Pasture Head to Nelson.

The following note on Nelson Corporation Waterworks are of interest:—

### *Rainfall.*

Average yearly rainfall in Nelson, no gauge.
" " " on Ogden gathering ground, no gauge.
" " " on Coldwell " " 30 inches.

*Capacity, &c., of Coldwell Reservoir.*

| Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|
| Gallons. | O.D. | Feet. | Acres. |
| 80,000,000 | 943·00 | 59 | About 18. |

(The capacity of "Wades" House Service Reservoir is 2,000,000 gallons, and its top water level 718·5 feet.)

### *Drainage Area.*

Ogden gathering ground, when all utilised, 1,100 acres (exclusive of compensation area).

Coldwell gathering ground, 400 acres, in addition to which the Corporation can take water from springs having above them a drainage area of 9,600 acres—the water from which does not go through Coldwell Reservoir.

### *Consumption of Water.*

700,000 to 800,000 gallons a day.

Yield of water from Ogden, 400,000 gallons a day (with no reservoir).

Yield of water from Coldwell, 515,000 gallons a day (excluding compensation water).

### *Notes on the Characters of the Gathering Ground.*

*Coldwell System.*—The gathering ground is moorland in character. The surface soil on the higher portions of the gathering ground is peaty, and supports the growth of moss and heather. Lower down the soil is much less peaty, and the vegetation is chiefly composed of rough pasture grass. The rock underlying the surface soil is chiefly sandstone and shale, belonging to the coal measure series, and millstone grit under the higher portion of the area.

The slopes of the hills are sufficiently steep to cause the rain to run rapidly off the surface. There are very few places where the rain stagnates in the soil. The moorland streams supplying Coldwell Reservoir run for the most part on rocky beds, or on clay bottom, and not on peaty soil. Besides the springs in the bed of the reservoirs, a large quantity of spring water finds its way into the streams, and these streams contain only a comparatively small amount of peaty water or water derived from surface drainage.

*Ogden System.*—The gathering ground is composed of moorland. Ogden Clough, the source of this system of water supply, yields a large amount of water. It runs a precipitous course along a rocky and sandy bed, and is fed laterally by numberless small streams, which drain land more or less peaty in character. The hills bounding Ogden Clough are very precipitous, and the rain falling on them runs rapidly away.

These hills are covered, not only with grass, but with heather and moss, and the soil covering is peaty. Owing to the abrupt slopes, however, the surface soil is thin, and in many places wanting, the underlying rock cropping out on the surface as rocky and sandy beds which successive rainfalls wash down into the valleys. The denudation taking place—especially in storm time—is considerable, large quantities of peat and disintegrated rock being carried downwards into and along the bed of Ogden Clough. A large amount of spring water enters this source of supply. There is also a considerable proportion of peaty water, or water from surface drainage, but since the rain does not stagnate in the soil its quality is not bad. The rock underlying the surface soil is chiefly Yoredale grit and shale.

### *Conditions found to exist on the Gathering Ground on April 2nd, 1896.*[*]

Lacmoid was used to test the reaction of the various waters examined.

*Coldwell System.*—The water in Coldwell Reservoir was neutral in reaction. The water in the streams (three) which supply this reservoir was neutral. These streams contain a mixture of spring water and of surface water, which is more or less peaty in character. Some of the smaller subsidiary streams were also tested, and with similar results. It is possible that in storm time the increase in the amount of surface water might alter the reaction of, at all events, some of these streams.

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[*] The daily rainfall previous to April 2nd, 1896, could not be ascertained as no gaugings were taken.

*Ogden System.*—Ogden Clough, both before and after filtration, was neutral in reaction. This stream was traced upward along part of its course, but the reaction of the water was found to be the same. Of the smaller streams entering Ogden Clough which were tested, all were found to contain neutral water. It is quite possible that in storm time Ogden Clough may contain an acid water, owing to the increase of peaty surface water as compared with spring water.

Samples of water were collected for more detailed examination from Coldwell Reservoir and from Ogden Clough. The examination of these waters showed that they were neutral, and free from plumbo-solvent ability. The results are given in an accompanying table.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

*Coldwell System.*—The following points are worthy of note as bearing on the observed neutral condition of the water, notwithstanding its moorland origin. There is a very considerable amount of spring water. Probably this spring water is not only neutral, but possesses some considerable acid neutralising ability. Supposing this to be the case, then it is probable that, even if some acid peaty water does gain access to the water supply, the spring water is more than sufficient in quantity to neutralise such acidity. A common source of acidity in moorland waters is from the rain stagnating in peaty and mossy pools. On this gathering ground the fall of the ground is sufficient to carry the water away fairly rapidly, and the peat is not deep.

The streams run on rocky beds, which are subject to renewal by denuding agencies. As bearing on the neutral condition of Coldwell Reservoir, it is to be noted that in flood time the streams are diverted, and instead of entering the reservoir, the water passes down a storm watercourse, and is used for compensation purposes.

On moorland gathering grounds, where there is a good growth of grass, the surface soil is usually only partially peaty in character, and is well drained. The water draining from such areas is usually neutral. It has been already shown that on this gathering ground grass grows over a large portion of the total area.

Briefly stated, the important points to be noted are:—The preponderance of spring water as compared with peaty water. The good drainage of the soil. Peat is not very abundant, either superficially or in depth.

*Ogden System.*—Much that has been already said of the Coldwell system applies equally here. The peat appears to be more abundant on this gathering ground, but it is especially to be noted that the sides of the hills are extremely precipitous, thus allowing the rain to run rapidly off the surface, and preventing it from stagnating in the soil.

Comparing the two systems of water supply, it is of interest to note that Coldwell springs are said to come from a greater depth of soil, and to yield "harder" water than Ogden springs. Probably a smaller quantity of Coldwell than of Ogden spring water would be needed to neutralise surface peaty water. The Ogden appears to contain more surface water than the Coldwell supply, but owing to the very rapid drainage of the soil on the Ogden gathering ground, it is perhaps of better quality than the water derived from Coldwell, where the slopes are much less abrupt and precipitous.

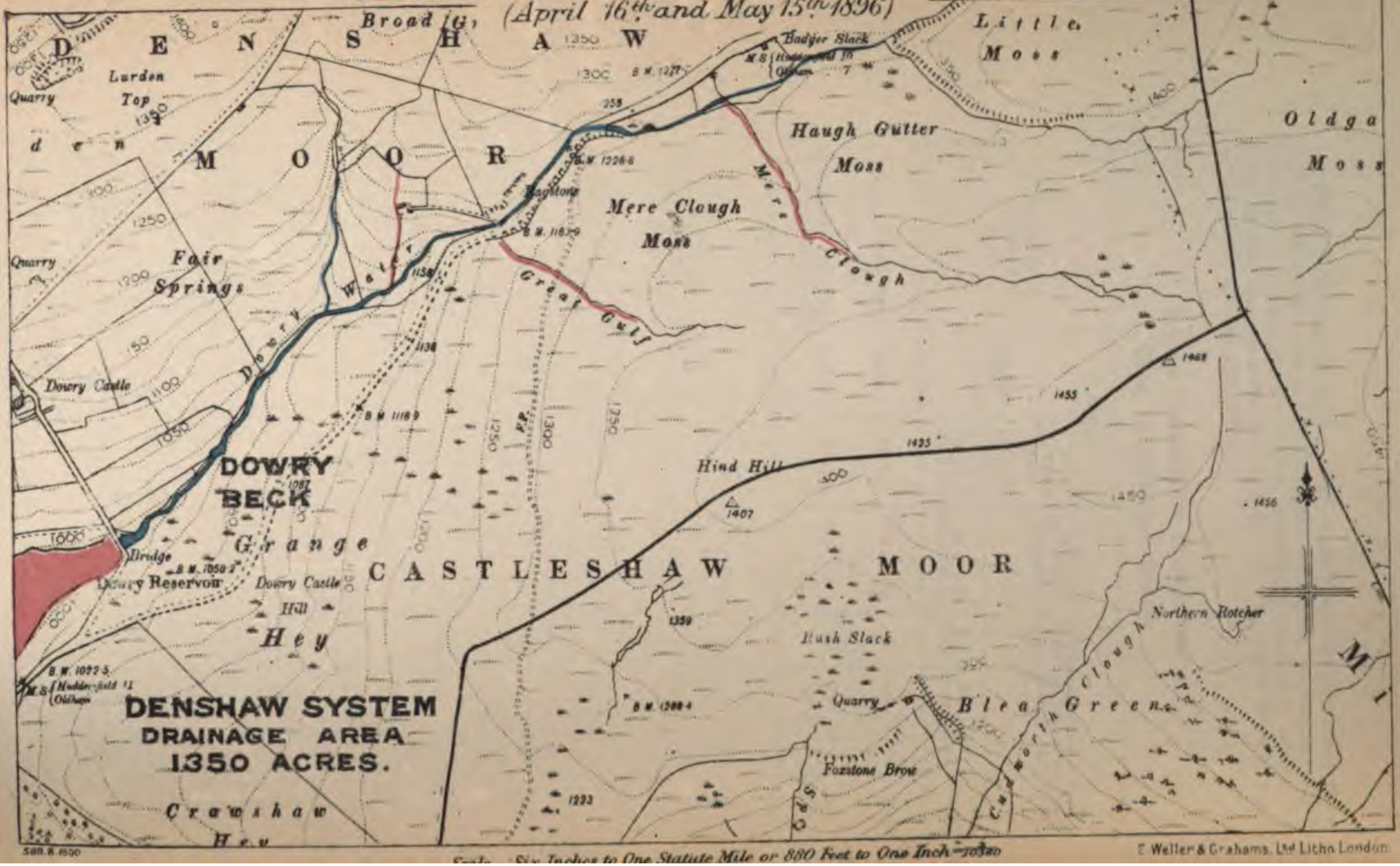
## NELSON CORPORATION WATERWORKS.

### *Table* 17.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Acidity. | | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Reaction with Lacmoid. | In Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | Ogden Clough water before filtration, April 4th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 2 | Coldwell Reservoir water, April 4th, 1896. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0· | 0·0 |

# OLDHAM CORPORATION WATERWORKS.

(April 16th and May 15th 1896)



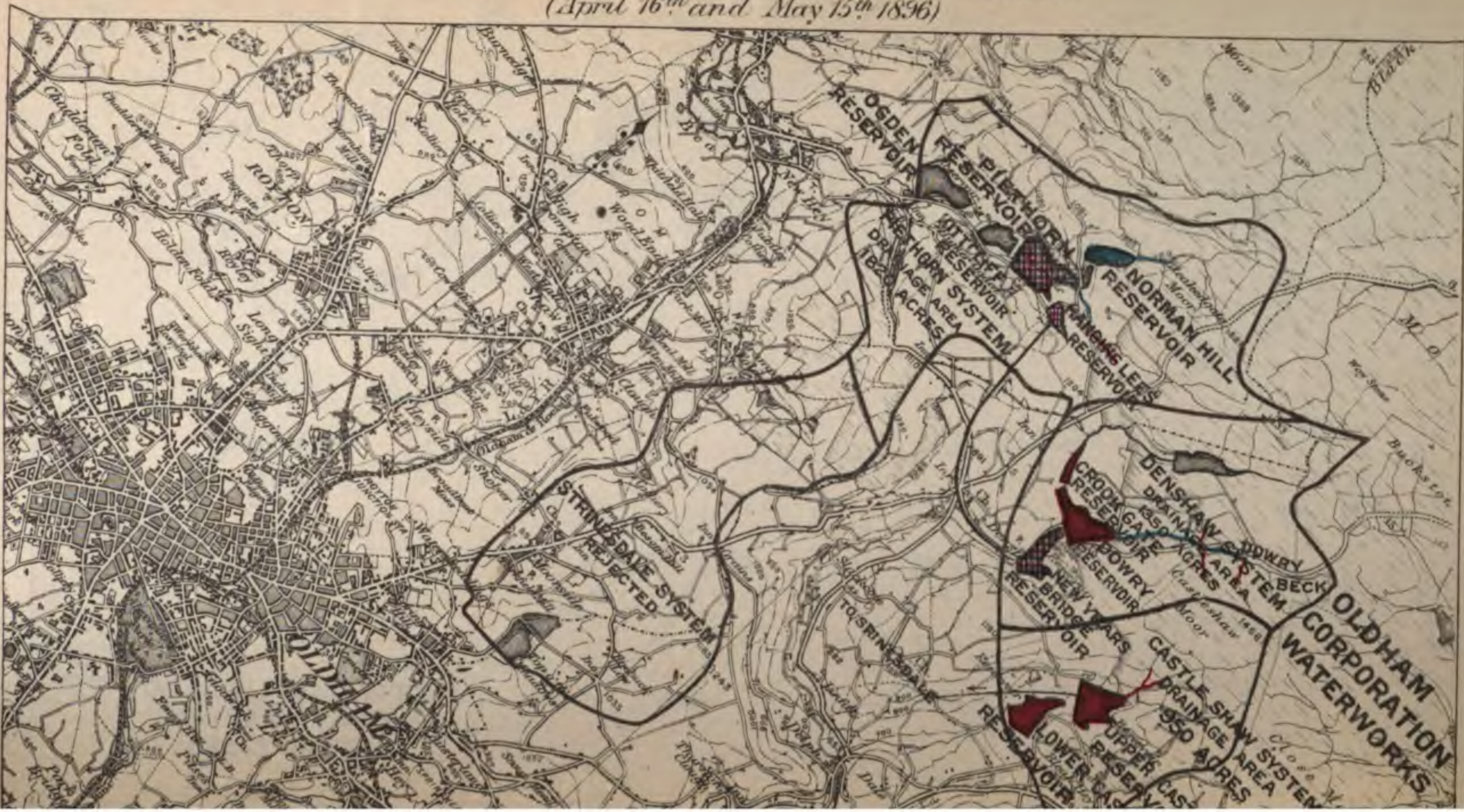
DENSHAW SYSTEM
DRAINAGE AREA
1350 ACRES.

Scale. Six Inches to One Statute Mile or 880 Feet to One Inch = $\frac{1}{10560}$

E. Weller & Grahams, Ltd Litho London.

## OLDHAM CORPORATION WATERWORKS.

(*April 16th and May 15th 1896*)



## Survey No. 18.

## OLDHAM CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland gathering grounds at Strinesdale, Piethorn, Denshaw, and Castleshaw, two, seven, six, and five miles from Oldham respectively.

The water from Strinesdale Waterworks has been rejected, and is now used only for compensation purposes.

*Denshaw System.*—There are four reservoirs on this gathering ground, the water from which is dealt with as follows:—A moorland stream supplies Readycon Dean, and the water from this reservoir passes into Crook Gate Reservoir. Dowry Reservoir receives the water from Crook Gate and from Dowry Beck, and discharges into New Year's Bridge. From this latter reservoir the water is conveyed by a tunnel and line of pipes to Hanging Lees Reservoir. Dowry Beck drains a large area of moorland. At its lower end a wreck lodge is provided to keep back peat and débris from entering Dowry Reservoir. Flood water is excluded from all the reservoirs used for domestic purposes by means of storm-watercourses.

*Piethorn System.*—There are five reservoirs (and a sixth in course of construction), two of which, Ogden and Kitcliffe Reservoirs, are used only for compensation purposes. The course taken by the water is as follows:—The water from the Denshaw System is brought, by way of a tunnel, to Hanging Lees Reservoir. A main carries the water from this reservoir to the higher parts of Oldham, but most of the water is allowed to pass into Piethorn Reservoir, and from thence it is conveyed by another main to Oldham. Piethorn Reservoir is also supplied with water from Norman Hill Reservoir, which, in turn, receives its supply from a moorland stream draining 480 acres. Storm-water is not allowed to enter the reservoirs, and is carried to compensation by a storm-watercourse. Storm-watercourses exist also in connexion with all the other systems of water supply.

*Castleshaw System.*—There are two reservoirs, Upper and Lower Castleshaw, on this gathering ground. The main source of supply is from Cudworth Beck, which supplies the upper reservoir. From Upper Castleshaw Reservoir the water passes direct to Strinesdale for distribution in the borough. The flood water passes into the lower reservoir. The main streams at Castleshaw are pitched to the crest of the hill, with the object of preventing the denudation of the sides of the valleys.

The Corporation own all the land bordering the reservoirs, and the watershed is free from all sources of pollution.

The water is delivered to the town of Oldham without filtration.

The following notes on Oldham Corporation Waterworks are of interest:—

### *Notes on Oldham Corporation Waterworks.*

### *Rainfall.*

| | |
|---|---|
| Average yearly rainfall in Oldham - - | 36 inches, |
| „ „ „ on gathering ground - | 42 „ |

## *Area, Top Water Level, Depth, and Capacity of the Chief Reservoirs.*

| — | Area, in Acres. | Top-Water Level, in Feet. | Depth, in Feet. | Capacity, in Gallons. |
|---|---|---|---|---|
| Piethorn Reservoir - - | 40 | 823 | 58 | 368,000,000 |
| Ogden Reservoir - | 31¼ | 690 | 38½ | 146,000,000 |
| Hanging Lees Reservoir - | 4½ | 884 | 30 | 31,000,000 |
| Kitcliffe Reservoir - - | 12 | 757 | 27 | 60,000,000 |
| Norman Hill Reservoir - | 8 | 911 | 45 | 60,000,000 |
| New Year's Bridge Reservoir | 14¾ | 945 | 55 | 91,000,000 |
| Dowry Reservoir - - | 23 | 1,000 | 54 | 163,000,000 |
| Crook Gate Reservoir - | 7½ | 1,052 | 49 | 41,000,000 |
| Readycon Dean Reservoir - | 14 | 1,268 | 48 | 86,000,000 |
| Upper Castleshaw Reservoir - | 30½ | 843 | 64 | 253,000,000 |
| Lower Castleshaw Reservoir - | 26 | 762 | 43 | 186,000,000 |

### *Drainage Area.*

| | | |
|---|---|---|
| Piethorn System - - | 1,820 acres | Total, 4,120. |
| Denshaw System - - | 1,350 „ | |
| Castleshaw System - - | 950 „ | |
| Strinesdale System - - | 1,360 „ | Rejected. |

### *Consumption of Water.*

3,274,560 gallons, on 307 days in the year

### *Rainfall for March* 1896.

| Date. | Stations. | | | |
|---|---|---|---|---|
| | Piethorn. Gold Creave. | Denshaw. New Year's Bridge. | Castleshaw. | Strinesdale. |
| | Height of Gauge above Sea Level, 894 Feet. | Height of Gauge above Sea Level, 1,012 Feet. | Height of Gauge above Sea Level, 875 Feet. | Height of Gauge above Sea Level, 815 Feet |
| 1896. | Inches. | Inches. | Inches. | Inches. |
| March 1 - | 0·05 | 0·12 | 0·11 | 0·09 |
| „ 2 - | 0·45 | 0·51 | 0·57 | 0·35 |
| „ 3 - | 0·08 | 0·09 | 0·11 | 0·08 |
| „ 4 - | 0·20 | 0·33 | 0·40 | 0·21 |
| „ 5 - | 0·20 | 0·28 | 0·28 | 0·15 |
| „ 6 - | 0·38 | 0·35 | 0·37 | 0·26 |
| „ 7 - | 0·62 | 0·76 | 0·80 | 0·67 |
| „ 8 - | 0·18 | 0·16 | 0·04 | 0·15 |
| „ 9 - | 0·05 | 0·10 | 0·08 | 0·07 |
| „ 10 - | 0·26 | 0·41 | 0·30 | 0·22 |
| „ 11 - | — | 0·08 | 0·07 | 0·03 |
| „ 12 - | — | — | — | — |
| „ 13 - | 0·36 | 0·46 | 0·33 | 0·29 |
| „ 14 - | 0·02 | — | 0·10 | — |
| „ 15 - | 0·50 | 0·56 | 0·51 | 0·39 |
| „ 16 - | 0·05 | 0·05 | 0·04 | 0·06 |
| 17 - | 0·13 | 0·23 | 0·28 | 0·18 |

## *Rainfall for March* 1896—continued.

| Date. | Stations. | | | |
|---|---|---|---|---|
| | Piethorn. Gold Creave. | Denshaw. New Year's Bridge. | Castleshaw. | Strinesdale. |
| | Height of Gauge above Sea Level, 894 Feet. | Height of Gauge above Sea Level, 1,012 Feet. | Height of Gauge above Sea Level, 875 Feet. | Height of Gauge above Sea Level, 815 Feet. |
| 1896. | Inches. | Inches. | Inches. | Inches |
| March 18 - | — | — | — | — |
| " 19 - | 0·04 | 0·06 | 0·06 | 0·01 |
| " 20 - | 0·10 | 0·12 | 0·10 | 0·06 |
| " 21 - | 0·01 | — | — | — |
| " 22 - | 0·03 | 0·09 | 0·08 | 0·09 |
| " 23 - | — | — | — | — |
| " 24 - | 0·07 | 0·12 | 0·13 | 0·09 |
| " 25 - | 0·20 | 0·15 | 0·16 | 0·07 |
| " 26 - | 0·38 | 0·62 | 0·51 | 0·39 |
| " 27 - | 0·40 | 0·27 | 0·24 | 0·28 |
| " 28 - | 0·05 | 0·29 | 0·24 | 0·28 |
| " 29 - | 0·01 | 0·05 | 0·06 | 0·03 |
| " 30 - | — | — | — | — |
| " 31 - | — | — | — | — |
| | 4·82 | 6·26 | 5·97 | 4·50 |

## *Rainfall for April*, 1896.

| 1896. | Inches. | Inches. | Inches. | Inches. |
|---|---|---|---|---|
| April 1 - | — | — | — | — |
| " 2 - | 0·04 | 0·08 | 0·05 | 0·06 |
| " 3 - | — | — | 0·02 | 0·03 |
| " 4 - | — | 0·03 | — | 0·05 |
| " 5 - | — | — | 0·02 | — |
| " 6 - | — | — | — | — |
| " 7 - | — | — | — | — |
| " 8 - | — | — | — | — |
| " 9 - | 0·06 | 0·11 | 0·11 | 0·03 |
| " 10 - | 0·17 | 0·12 | 0·13 | 0·08 |
| " 11 - | 0·05 | 0·09 | 0·08 | 0·06 |
| " 12 - | 0·04 | 0·10 | 0·07 | 0·10 |
| " 13 - | 0·10 | 0·16 | 0·17 | 0·11 |
| " 14 - | 0·08 | 0·12 | 0·11 | 0·17 |
| " 15 - | 0·11 | 0·15 | 0·13 | 0·09 |
| " 16 - | 0·28 | 0·36 | 0·42 | 0·29 |
| " 17 - | — | — | — | — |
| " 18 - | — | — | — | — |
| " 19 - | — | — | — | — |
| " 20 | — | — | — | — |
| " 21 - | — | — | — | — |
| " 22 - | — | — | — | — |
| " 23 - | — | — | — | — |
| " 24 - | — | — | — | — |
| " 25 - | 0·05 | 0·11 | 0·08 | 0·08 |
| " 26 - | 0·03 | 0·04 | 0·03 | 0·01 |
| " 27 - | 0·25 | 0·24 | 0·21 | 0·20 |
| " 28 - | 0·25 | 0·12 | 0·14 | 0·12 |
| " 29 - | 0·01 | 0·05 | 0·03 | 0·08 |
| " 30 - | 0·10 | 0·16 | 0·20 | 0·03 |
| | 1·62 | 2·04 | 2·00 | 1·59 |

### *Rainfall for May*, 1896.

| Date. | Stations. | | | |
|---|---|---|---|---|
| | Piethorn. Cold Greave. | Denshaw. New Year's Bridge. | Castleshaw. | Strinesdale. |
| | Height of Gauge above Sea Level, 894 Feet. | Height of Gauge above Sea Level, 1,012 Feet. | Height of Gauge above Sea Level, 875 Feet. | Height of Gauge above Sea Level, 815 Feet. |
| 1896. | Inches. | Inches. | Inches. | Inches. |
| May 1 - | — | — | — | — |
| „ 2 - | — | — | — | — |
| „ 3 - | — | — | — | — |
| „ 4 - | — | — | — | — |
| „ 5 - | — | — | — | — |
| „ 6 - | — | — | — | — |
| „ 7 - | — | — | — | — |
| „ 8 - | — | — | — | — |
| „ 9 - | — | — | — | — |
| „ 10 - | — | — | — | — |
| „ 11 - | — | — | — | — |
| „ 12 - | — | — | — | — |
| „ 13 - | — | — | — | — |
| „ 14 - | — | — | — | — |
| „ 15 - | — | — | — | — |
| „ 16 - | — | — | — | — |
| „ 17 - | — | — | — | — |
| „ 18 - | 0·05 | 0·15 | 0·14 | 0·07 |
| „ 19 - | 0·09 | 0·16 | 0·15 | 0·11 |
| „ 20 | 0·02 | 0·09 | 0·02 | 0·05 |
| „ 21 - | 0·45 | 0·49 | 0·43 | 0·40 |
| „ 22 - | 0·04 | 0·07 | 0·03 | 0·01 |
| „ 23 - | — | — | — | — |
| „ 24 - | — | — | — | — |
| „ 25 - | — | — | — | — |
| „ 26 - | — | — | — | — |
| „ 27 - | — | — | — | — |
| „ 28 - | — | — | — | — |
| „ 29 - | — | — | — | — |
| „ 30 - | — | — | — | — |
| „ 31 - | — | — | — | — |
| | 0·65 | 0·96 | 0·77 | 0·64 |

### *Notes on the Characters of the Gathering Ground.*

The whole of the gathering ground is composed of moorland, and the surface soil is peaty in character. The amount of peat varies very much on the gathering ground. There are large areas where the soil is only partially peaty. The soil is usually most peaty and deepest on the higher and flatter portions of the gathering ground. On the slopes of the hills the soil is thin, and where the sides of the valleys are very precipitous the underlying rock appears on the surface. The vegetation consists for the most part of coarse grass in an active stage of growth, but heather is abundant in many places, particularly where there exists much decaying vegetable matter and boggy land. Briefly stated, it would seem that where the soil is least peaty, and well drained, grass grows most freely, but that where the soil is boggy in character heather and moss flourish. The surface soil rests on grit or shale, and the peat beds overlie a layer of clay 12 to 18 inches thick. The denudation on the slopes of the hills is very considerable, and in storm time large quantities of disintegrated rock, as well as peaty matters, are carried down the watercourses. Nearly all the water draining from the gathering ground has a rapid fall, but high up on the hills there is a considerable opportunity afforded to the water of stagnating in the peat. Much of this peaty water, however, fails to reach the water works, as it is only washed into the streams during flood time, and the exceptional control of the reservoirs with storm-watercourses prevent its contaminating the water supply. The streams mainly run over rocky and sandy beds for considerable distances before being collected for waterworks purposes.

Passing briefly in review the different systems of supply, it may be stated that the Piethorn System appears to receive least, and the Castleshaw System most peaty water. The former certainly drains land less peaty than the latter. On one portion of the Piethorn gathering ground ditches have been cut to prevent the rain from stagnating in the soil. The effect of this has been to stimulate the growth of grass on the surface, and to improve the quality of the water draining therefrom. Similar improvements have been carried out on other portions of the gathering ground, and in general the attempt has been made to get the water in bulk into the reservoirs as soon as possible. The upper reaches of Cudworth and Dowry Becks drain lands exceptionally peaty, but—and this especially in the case of Dowry Beck—much of the water in ordinary conditions of rainfall is held by the peat or lies in bog holes, and can only be washed into the watercourses in flood time, when it is not permitted to reached the reservoirs. The moorland stream supplying Readycon Dean Reservoir derives its water from a peaty area comparable to the area drained by Dowry Beck.

### *Conditions found to exist on the Gathering Ground on April 16th and May 15th*, 1896.

The rainfall previous to April 16th and May 15th was below the average. The rainfall for March, April, and May is given in accompanying tables.

The reaction of the water in the reservoirs and in the moorland streams was tested with an alcoholic solution of lacmoid.

*Piethorn System.* April 16th, 1896.—The water in Kitcliffe and Ogden Reservoirs is used for compensation purposes, and so no test was made of the reaction of this water. The water in Piethorn Reservoir was only very slightly acid, and so was the water entering Piethorn Reservoir from Hanging Lees Reservoir. The water issuing from the tunnel which conveys the water from the Denshaw System to Hanging Lees, and the water in Hanging Lees Reservoir, appear to contain only traces of acid.

The water from the main moorland stream supplying Piethorn Reservoir was neutral in reaction, and so was the water from Cold Greave Clough. The latter, however, traced upwards towards its source, became gradually acid, a fact to be attributed probably to the presence of more peaty and less spring water in its upper part. It is not unlikely that Piethorn and Cold Greave Cloughs yield an acid water in flood time, when the proportion of spring water to surface drainage water is lessened. The arrangement of the storm-watercourses is such, however, that flood water is not permitted to enter the water supply, and is used instead for compensation purposes.

Water is also piped to Piethorn Reservoir from land which is perhaps exceptionally peaty. This area has been carefully drained by ditches and pipes, and with the result that where the vegetation was scanty before, grass now flourishes. The water from the various drains is discharged by a common pipe into Piethorn Reservoir, and this water was found to be slightly acid in reaction. It is reasonable to suppose, however, that the improved drainage would lessen the acidity of this water by preventing the rain from stagnating in, and saturating the peaty soil. Other and similar areas exist on this gathering ground which are drained in the same way.

*Castleshaw System.* April 16th, 1896.—The water in Upper and Lower Castle Shaw Reservoirs was acid. The main moorland stream supplying this waterworks system is Cudworth Beck, and the water in it, as well as in some of its chief tributary feeders, was found to be distinctly acid. As has been already described, Cudworth Beck drains land exceptionally peaty in character. The pitching of the lower part of the bed of this stream, while it prevents denudation of the hill slopes, may also prevent a certain amount of neutralisation of the water. It seems that the flow of water along a rocky bed, and the constant washing down of rock and sand from the hill sides, has a certain neutralising effect in the case of an acid moorland water.

*Denshaw System.* May 15th, 1896.—The water in New Year's Bridge Reservoir appeared to be faintly acid in reaction. The water in Crook Gate and Dowry Reservoirs was acid. The water in Readycon Dean Reservoir and its main feeder was not tested, but it is probable that it is—at all events occasionally—acid, since Crook Gate Reservoir takes its supply from this source. Dowry Beck—the water in which was running very low owing to the prolonged drought—was tested at intervals along its entire course, and found to be neutral. Four of its chief tributary feeders were tested : one was neutral, but the other three were acid in reaction. In its upper part Dowry Beck receives neutral water from a number of small "ochre" springs. The water from these springs loses most its iron as soon as it issues from the ground. Owing to the prolonged drought hardly any water was draining from the surface soil. The water lay, however, stagnating in peat holes, and when tested with lacmoid gave a distinctly acid reaction. A sample of water was obtained from one of these peat holes, and it was noted whilst collecting it that the water was quite warm to the touch. Much of the peat on this, as well as on other parts of the gathering ground, rests on clay. From the nature of the collecting ground it seems likely that Dowry Beck contains an acid water in storm time. The amount of shale and sand washed down the beck from the slopes of the hills in storm time is very great, and a large "wreckage" lodge is provided at its lower end to deal with this matter. It is to be noted that this extensive denudation of the hills may be a not unimportant factor in bringing about the neutralisation of the water.

Flood water is excluded from the water supply by storm watercourses.

Samples of water were collected for detailed examination from New Year's Bridge, Piethorn, and Upper Castle Shaw Reservoirs, from Dowry and Cudworth Becks, from the Tunnel Exit from the Denshaw System, and from a depression in the peat at or near the origin of Dowry Beck. Later a sample of water from Readycon Dean Brook was examined, and also a sample of water from Dowry Beck in heavy flood.

The results of the examination of these waters is shown in an accompanying table. Briefly, the analysis of these waters showed that the water from Piethorn, New Year's Bridge, and Upper Castle Shaw Reservoirs, and the water from the Tunnel Exit from the Denshaw System was slightly acid, and dissolved lead to a small extent, that the water from Dowry Beck was neutral, and free from plumbo-solvent ability, and that the water from Cudworth Beck was distinctly acid, and acted distinctly on lead. The water from the bog hole near the origin of Dowry Beck was extremely acid, and dissolved lead in a very marked manner. The sample of water from Readycon Dean Brook, obtained at a later date, was neutral, and free from plumbo-solvent ability. The water in this stream was running very low at the time the sample was collected, and it is probable, from the peaty nature of the ground which it drains, that it would be acid in flood time.

A sample of water obtained from Dowry Beck in heavy flood was found to be very acid, and to act on lead in a marked manner.

With regard to the waters tested on the gathering ground, but not collected for more detailed examination, it is to be noted that when a water gives a neutral, or only a very faint acid reaction with lacmoid, it will not dissolve lead under laboratory conditions of experiment to any appreciable extent.

### *Remarks on the Results yielded by the Chemical Examination in reference to the observed Character of the Gathering Ground.*

It is to be noted that the character of the gathering ground is such that it might be expected that the reservoirs would contain water more acid than was actually found to be the case. Doubtless the adequate provision of storm-watercourses to carry off the flood-water in connexion with all the systems of water supply, and the somewhat unique conditions of supply, by which the water is conveyed by gravitation from reservoir to reservoir, have much to do with the observed quality of the water.

Passing briefly in review the different systems of water supply, the following points are to be noted:—

*Piethorn System.*—The water in Piethorn Reservoir was found to be slightly acid, and to possess some plumbo-solvent ability. This acidity appears to be derived from the Denshaw System of supply, and perhaps also from the moorland streams which enter the upper end of the reservoir. These streams drain moorland which is not very rich in peat, which does not afford exceptional opportunities for the stagnation of the rain in the soil, and which is covered, for the most part, with an active growth of grass. Nevertheless, it is not unlikely that these streams may contain acid water when the proportion of surface drainage water to spring water is largely increased, and it is possible that the storm-watercourses may carry only the worst portion of this water to compensation, and that the purer, but still acid water, may occasionally be permitted to pass into the waterworks supply.

Reference has already been made to a small but acid supply of water, piped to the reservoir from land carefully drained but somewhat rich in peat. This water is probably too small in amount to affect prejudicially the body of water in Piethorn Reservoir.

*Denshaw System.*—The water in New Year's Bridge Reservoir was only very slightly acid in reaction, and its action on lead was inconsiderable. Dowry Reservoir, which supplies the above, appeared to contain a more acid water, the acidity probably being derived from Crook Gate, which in its turn is supplied from Readycon Dean, the supply to the latter reservoir being from a moorland stream which drains land exceptionally peaty. Dowry Beck was neutral, but it is more than probable that in storm time it contains an acid water, and it is possible that some of this acid water gains an entrance into Dowry Reservoir, notwithstanding the provision of a storm-watercourse. A sample of water obtained at a later date from Dowry Beck in heavy flood was found to be very acid, and it acted on lead to a remarkable extent. The neutral condition of Dowry Beck on May 15th may be traced to the fact that almost all the water in it was derived from springs, and very little from surface drainage. The precipitous slopes of the hills along the lower part of its course, and the rocky bed on which the water runs, probably tends to improve the quality of this supply even in flood time. It has been already remarked that the extensive denudation of the sides of the valleys may be beneficial in the way of neutralising any acid in the water. So far as could be seen, those of its tributaries which were found to be acid drained peaty land, and those which were neutral contained chiefly spring water. The extraordinary acidity of the water collected from one of the depressions in the peat at or near the origin of Dowry Beck, appears to be due to the rain saturating and lying stagnant in peat several feet in thickness, and resting on clay 12 to 18 inches in depth. On this portion of the gathering ground the lateral fall of the water is very slight, and since the peat rests on clay, there is little opportunity afforded to the rainfall of sinking into the underlying rock. Hence the rain saturates the peat, accumulates in depressions, and escapes only by slow percolation in a lateral direction. Nevertheless, it is to be noted that very little of this water appears to reach Dowry Beck, unless in storm time.

*Castleshaw System.*—The main streams supplying Upper Castleshaw Reservoir are pitched to the crest of the hill, and while this arrangement limits the denudation of the hill sides and so probably reduces the amount of peaty and solid matters entering the reservoir, it perhaps also prevents a certain amount of neutralisation of the acid water by contact with sand and rocky debris. However this may be, it is certain that Cudworth Beck is distinctly acid, and dissolves lead to a considerable extent. Its acidity appears to be derived from the drainage of exceptionally peaty land.

The water in Upper Castleshaw Reservoir, as might be expected, was also acid, and dissolved lead to an appreciable extent.

In conclusion, the following points deserve consideration. The acidity of the various waters appeared to be traceable to the more or less prolonged contact of rain water with peat. This was especially observed on the upper and flatter portions of the gathering ground, where the peat was several feet in thickness, and rested on clay, and where the fall was too slight to allow of efficient drainage. The neutral, or nearly neutral, condition of some of the waters seemed to be due to the comparative absence of peaty water and the presence of spring water. Other agencies at work which might be expected to control the acidity of the waters gaining entrance to the reservoirs have been already alluded to, *e.g.*, the provisions of storm-watercourses, the flow of the water on rocky and sandy beds, &c.

## OLDHAM CORPORATION WATERWORKS.

### TABLE 18.—*Chemical Results*:

| Experiment. | Description of the Sample of Water. | Acidity. |  | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Reaction with Lacmoid. | In Terms of c.c. $\frac{n}{10}Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average |
| 1 | April 16th, 1896. Piethorn Reservoir. | Slightly acid. | 0·20 | 0·1 | 0·4 | 0·4 | 0·4 | 0·4 | 0·34 |
| 2 | May 16th, 1896. Piethorn Reservoir. | Slightly acid. | 0·20 | 0·1 | 0·1 | 0·2 | 0·2 | 0·2 | 0·16 |
| 3 | April 16th, 1896. Tunnel exit from Denshaw System. | Trace acid | Trace acid | Traces. |  |  |  |  |  |
| 4 | April 16th, 1896. Cudworth Beck—near inlet to Upper Castleshaw Reservoir. | Distinctly acid. | 0·54 | 0·6 | 0·8 | 1·0 | 1·0 | 1·2 | 0·92 |
| 5 | April 17th, 1896. Upper Castleshaw Reservoir. | Slightly acid. | 0·24 | 0·1 | 0·2 | 0·2 | 0·3 | 0·3 | 0·22 |
| 6 | May 16th, 1896. New Year's Bridge Reservoir. | Trace acid | 0·18 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 | 0·10 |
| 7 | May 16th, 1896. Dowry Beck—near inlet to Dowry Reservoir. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 8 | May 16th, 1896. Bog Hole about 1,450 feet above sea level and near origin of Dowry Beck. | Very acid | 2·20 | 6·0 | 8·0 | 9·0 | 10·0 | 10·0 | 8·00 |
| 9 | July 14th, 1896. Readycon Dean Brook. In time of drought. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 10 | August 3rd, 1896. Dowry Beck during heavy flood (1·52 inches of rain fell in 1¼ hours). | Very acid | 1·32 | 2·4 | 3·2 | 3·2 | 3·2 | 3·2 | 5·04 |

## Survey No. 19.

### PRESTON CORPORATION WATERWORKS.

### Source of the Water Supply and General Descriptio of the Waterworks.

The supply is obtained from moorland at Whitewell, about 20 m from Preston. There are two systems of water supply, known as Langden and Hareden Systems.

*Langden System.*—The water from the River Langden is car into a screen chamber, about 530 feet above sea-level. The sc contains 16 meshes (256 holes) to the square inch. The water, af screening, is conveyed in a covered conduit to the measuring basin i the Langden Valley.

*Hareden System.*—A similar arrangement to the above exists connexion with the Hareden Brook. The water from Hareden Brook carried into a screen chamber, about 475 feet above sea-level. Aft screening, the water is conveyed along a covered conduit to t measuring basin above mentioned, where it joins the water from t River Langden, after which it passes through the measuring bas along a covered conduit to Grimsargh Reservoirs.

From Alston Reservoir the water passes into the Grimsargh (Servic Reservoirs, three in number, and eventually through fine screens of ( meshes (3,600 holes) to the square inch, and direct to the town. T whole of the water from the River Langden and Hareden Brook is n available for waterworks purposes. The portion not used escapes alo the natural course of the streams as compensation water. In stor time none of the water is allowed to enter the screen chambers, bei turned down the stream by the servants of the Corporation.

The following notes on Preston Corporation Waterworks are interest :—

*Level of Intake on Screen Chambers at Rivers Langden and Hareden.*

About 530 and 475 feet above sea-level respectively.

*Delivery of Conduit from River Langden and Hareden Brook.*

6¼ million gallons per day (maximum).

*Level of Grimsargh Service Reservoirs above Sea-Level.*

234 feet.

*Capacity of Reservoirs.*

| | |
|---|---|
| Alston - - - | 84,217,354 gallons. |
| Grimsargh (3) - - - | 59,173,000 „ |

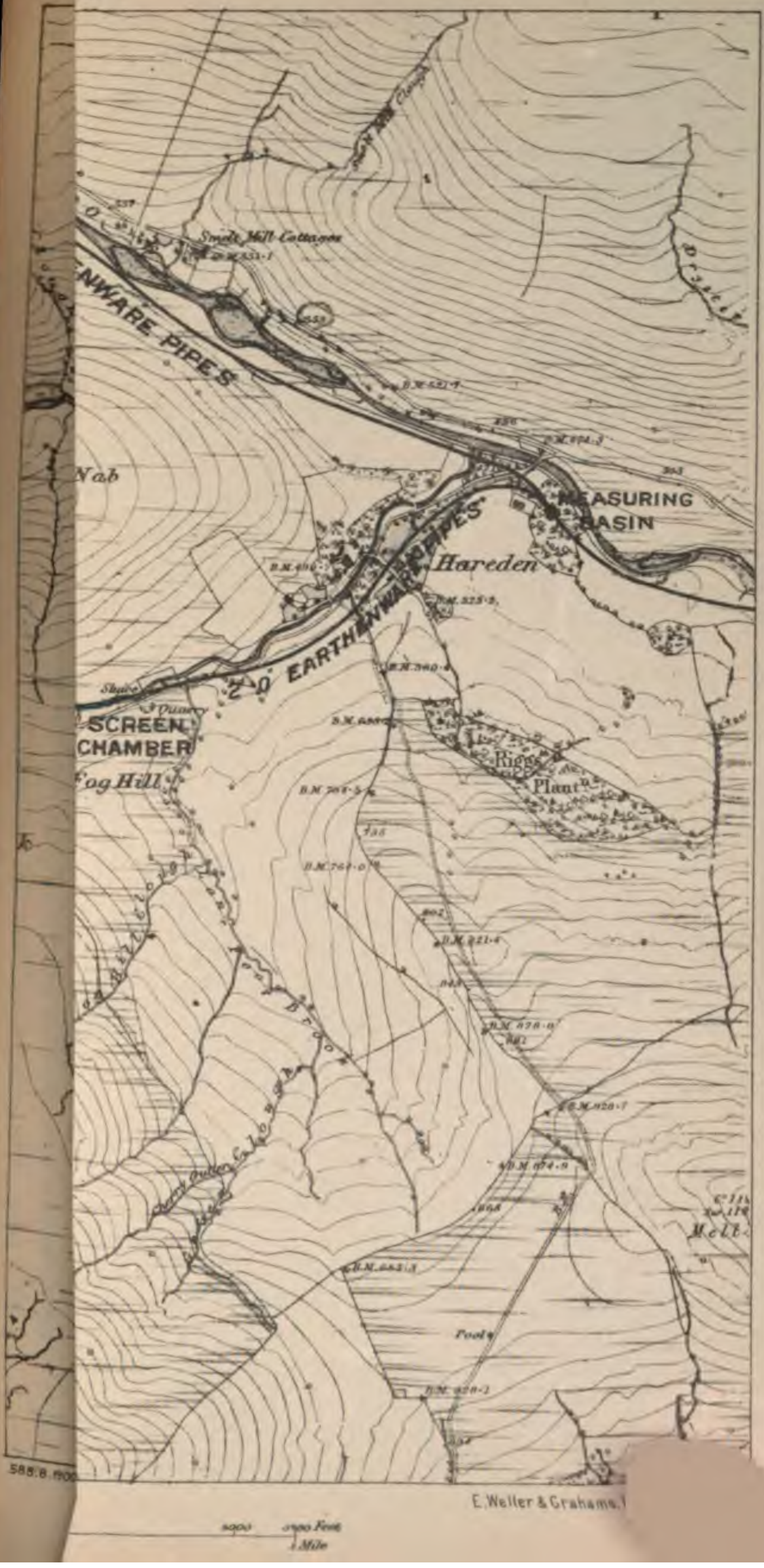
*Level of Screen Chamber at Grimsargh Service Reservoirs.*

222 feet above sea-level.

*Consumption.*

3¼ million gallons per day (average).

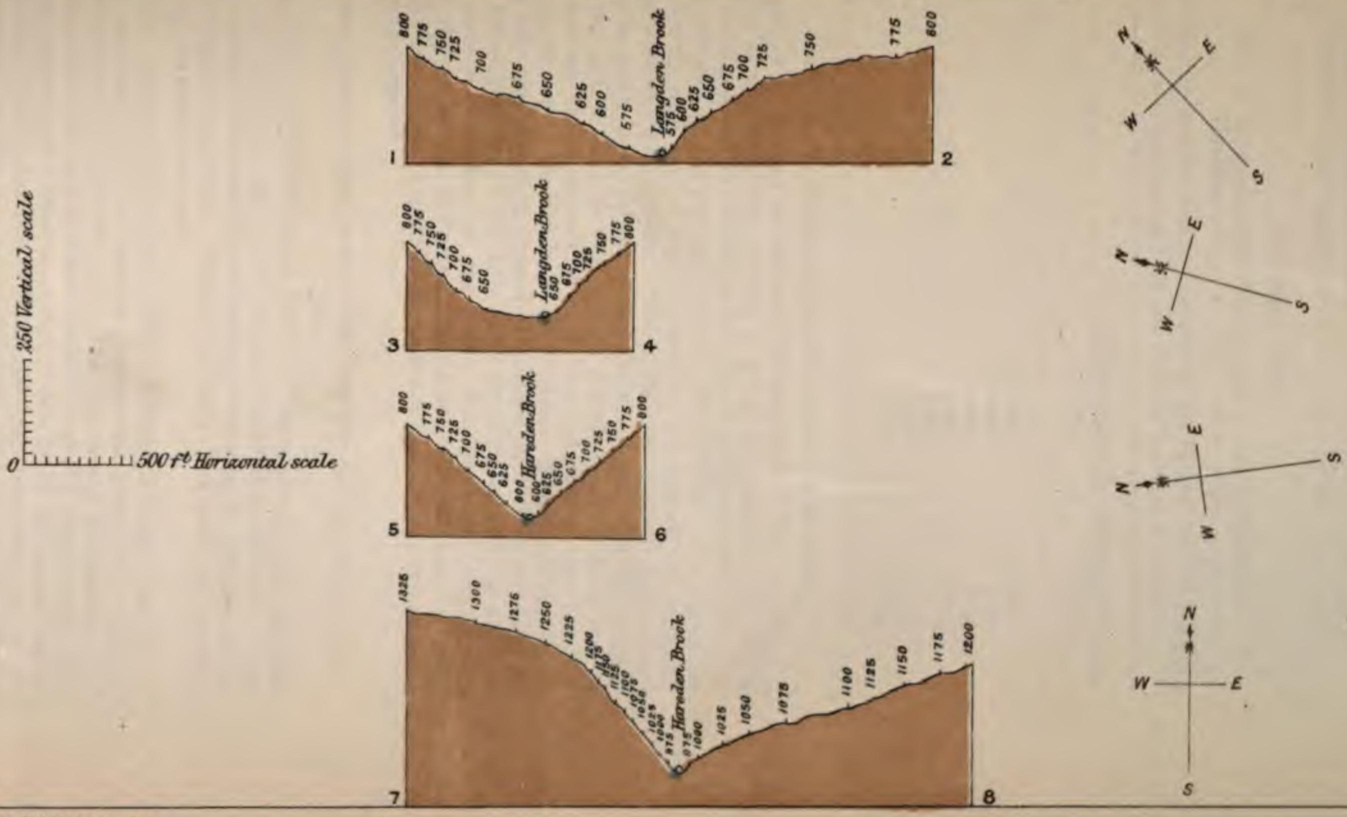
S.



588.8.1900

E. Weller & Grahams,

along certain lines marked 1,2;3,4;5,6;7,8; on accompanying 6" ordnance map. The points of the compass show the direction in which these lines run.



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588.6.1901

### *Average Yearly Rainfall for last Five Years.*

| | |
|---|---|
| Preston - - - - | 35·86 inches. |
| Langden gathering ground - - | 71·75 " |
| Hareden gathering ground - - | 73·33 " |

### *Drainage Area.*

| | |
|---|---|
| Area of Langden gathering ground - | 3,795 acres. |
| " Hareden " " - | 970 " |

The following are the monthly returns of the rainfall on the Langden and Hareden gathering ground for the first six months of 1896 :—

| 1896. | Langden Gathering Ground. | Hareden Gathering Ground. |
|---|---|---|
| | Inches. | Inches. |
| January - - - - | 6·50 | 6·60 |
| February - - - - | 6·75 | 6·80 |
| March - - - - | 10·80 | 10·85 |
| April - - - - - | 4·30 | 4·35 |
| May - - - - - | 0·80 | 0·85 |
| June - - - - | 4·45 | 4·30 |

### *Notes on the Characters of the Gathering Ground.*

The gathering ground is composed of moorland. The surface soil over most of the gathering ground is peaty in character. Its depth appears to be greatest on the higher and flatter portions of the gathering ground, and least on the precipitous slopes of the hills. The vegetation consists for the most part of coarse grass, but portions of the gathering ground are covered with heather. The surface soil rests on grit or shale which in its upper layers appear much disintegrated. On the slopes of the hill the surface soil is so thin that in places the underlying rock is visible, and has the appearance of sand beds. In storm time much of this sandy matter is washed into the streams. Nearly all the water draining from this gathering ground has a rapid fall. Possibly high up on the flatter portions of the hills some opportunity may be afforded to the water of stagnating in the peat. The water in Langden and Hareden Brooks, as well as in the main tributary streams, runs on rocky and sandy beds, and for a considerable distance, before being collected for waterworks purposes.

### *Conditions found to exist on the Gathering Ground on March* 10*th*, 1896.

The rainfall previous to March 10th was above the average, and the streams on the above date were running fuller than is usual. The monthly returns of the rainfall for the first six months of 1896 are given in an accompanying table. Lacmoid solution was used to test the reaction of the various waters.

*Langden System.*—The water after, passing through the screen chamber, and the water in Langden Stream was neutral in reaction. A number of small tributary streams to Langden Stream were tested. A few of these were acid, and appeared to contain chiefly peaty water, the rest were neutral, and contained spring water, or, at all events, water not essentially peaty in character. The water from these little tributaries yielding an acid reaction was not sufficient to alter the reaction of the body of water in Langden Brook.

*Hareden System.*—The water, after screening, and the water in Hareden Brook, was neutral. None of the small streams supplying Hareden Brook that were tested gave an acid reaction.

It is to be noted that a water which does not give a distinctly acid reaction with lacmoid will not dissolve lead to any appreciable extent under the conditions of experiment in the laboratory. Judged by this standard, the water from Langden and Hareden Systems may be regarded as free from plumbo-solvent ability.

Samples of water were collected for more detailed examination from Langden Stream, and an acid and peaty feeder supplying Langden Stream. Subsequenly a sample of water from Alston Reservoir and from the main supplying Preston was obtained and submitted to examination. The results are given in an accompanying table. It is to be noted that the only water which possessed an acid reaction and plumbo-solvent ability was the peaty water from a small tributary stream to Langden Brook.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

Preston and Blackburn gathering grounds adjoin each other, and the character of the ground and mode of obtaining the water supply is nearly the same in each case.

As explaining the neutral condition and freedom from action on lead of the water supplied to Preston—notwithstanding its moorland origin—the following points are to be noted. The bearing of these points on the quality of the water supply is discussed in the description of Mockburn Corporation Waterworks. The exclusion of storm water from the waterworks, the provision of screen chambers, the flow of the water for considerable distances along rocky and sandy beds, the precipitous slopes allowing of a rapid flow of water and efficient drainage of the soil, the comparative absence of peaty and boggy land, the shallowness of the peat beds, the active growth of vegetation, and the small proportion of peaty water to spring water or water not peaty in character.

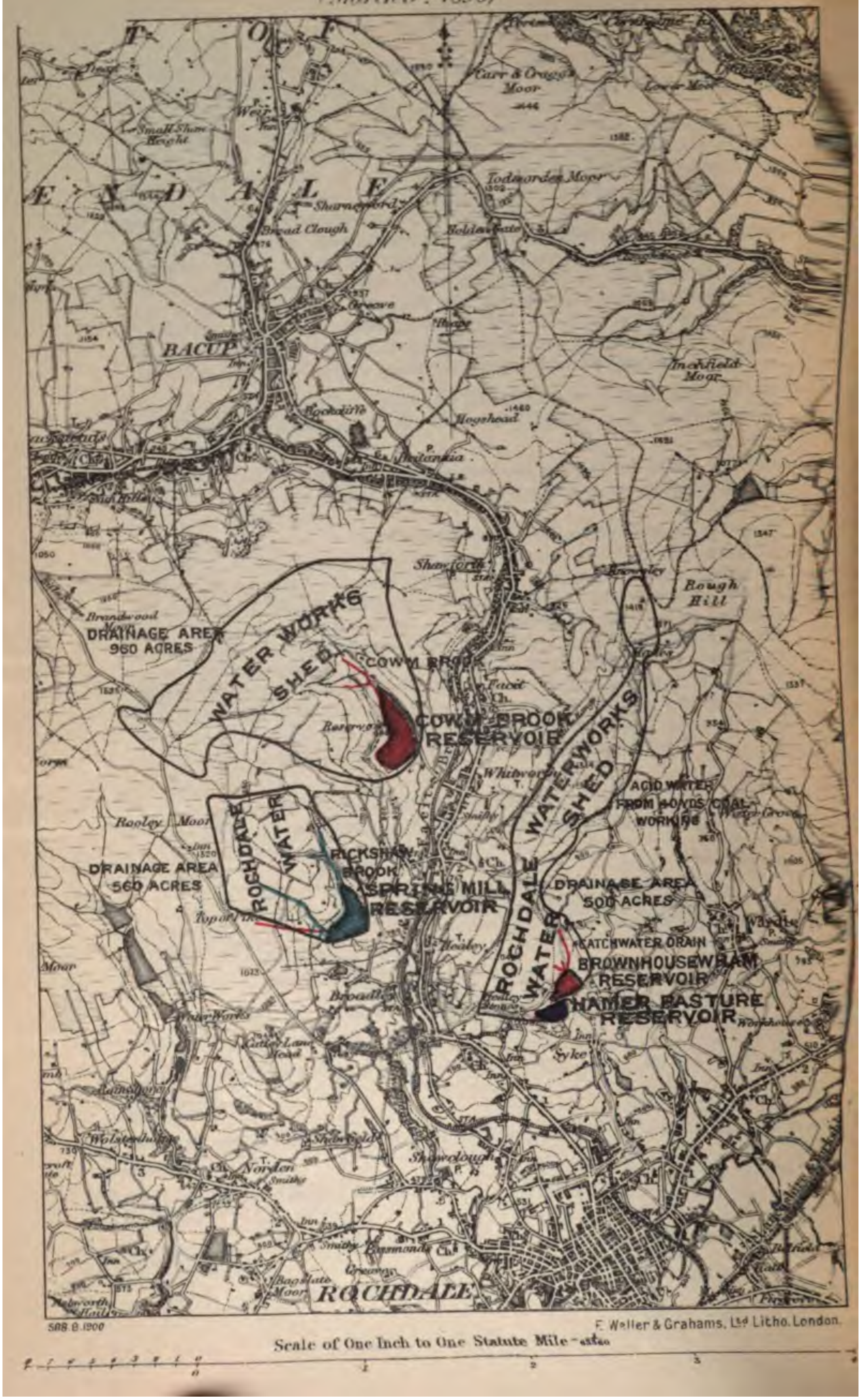
PRESTON CORPORATION WATERWORKS.

TABLE 19.—*Chemical and Bacteriological Results,*

| Experiment. | Description of the Sample of Water. | Acidity. | | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by means of upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | | Numbe Micro-Org in 1 c.c. c wate |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Reaction with Lacmoid. | In Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 0 c.c. | 4th 50 c c. | 5th 50 c.c. | Average. | |
| 1 | 11th March 1896, Langden Stream water before entering screen chamber. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | | 211 |
| 2 | 11th March 1896, small peat feeder to Langden Stream. | Acid | 0·36 | 0·2 | 0·4 | 0·5 | 0·5 | 0·5 | 0·42 | The plate crowded of the c being cou |
| 3 | 17th March 1896, water from Alston Reservoir, near outlet. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | — |
| 4 | 16th July 1896, Preston main water. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | — |

# ROCHDALE CORPORATION WATERWORKS.

*(March 3rd 1896)*



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E. Weller & Grahams, Ltd Litho. London.

Scale of One Inch to One Statute Mile

## Survey No. 20.

### ROCHDALE CORPORATION WATERWORKS.

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIPTION OF THE WATERWORKS.

The supply is obtained from moorland gathering grounds within a few miles from Rochdale. There are two sets of waterworks, the old and the new. The latter obtains its supply from two separate systems.

*Old Works.*—There are two reservoirs on this gathering ground, and the course taken by the water is as follows:—Two small mountain streams unite and enter Brownhouse Wham Reservoir at its upper end; here also enters the water from a catch-water drain which collects water from a large moorland area. The water passes from Brownhouse Wham into Hamer Pasture Reservoir, and is conveyed from thence by a single main to the town of Rochdale. There are no filter beds, but the water in Hamer Pasture Reservoir is treated with lime by means of boats, the lime (whiting—about 1 gr. to 1 gallon) being thrown with scoops on the surface of the water. Some distance from Brownhouse Wham Reservoir there is a 40-yards mine (Cartridge Nook Colliery). The water draining from this area used to reach the waterworks, but now is wholly rejected, as it was found that it contaminated the supply to a serious extent. No arrangements exist for preventing storm water from entering the reservoir.

*New Works.*—Here there are two separate systems of water supply.

*Cowm System.*—Cowm Reservoir receives its supply chiefly from Cowm Brook, a mountain stream draining a large area of moorland. The water from Cowm Reservoir is filtered through sand, and enough whiting is added to the water in the filter beds to cover the sand with a thin coating of lime. After filtration the water is carried in a single main to the town of Rochdale.

No arrangements exist for preventing storm water from entering Cowm Reservoir.

*Spring Mill System.*—The chief supply to Spring Mill Reservoir is Prickshaw Brook, which drains a considerable tract of moorland. A small mountain stream also enters the reservoir on the west side. The water is filtered through sand and whiting as at Cowm Reservoir. After filtration the water is carried in a single main to the town of Rochdale. No arrangements exist for excluding storm water from Spring Mill Reservoir.

The pipes from the Hamer Pasture, Spring Mill, and Cowm Reservoirs are connected together so that the water supply can be afforded either separately or in conjunction, as circumstances require.

The following notes on Rochdale Corporation Waterworks are of interest:—

*Rainfall.*

Average yearly rainfall in Rochdale, 42 inches.
" " " on gathering ground, 49 inches.

### *Area, Depth, and Capacity of Reservoirs.*

| Area. | Depth. | Capacity. |
|---|---|---|
| Cowm Reservoir, 40 acres - - - | 51ft. | 228,000,000 gallons. |
| Spring Mill Reservoir, 24 acres - - - | 46ft. | 134,000,000 „ |
| Brownhouse Wham Reservoir, 11 acres - | 26ft. | 47,000,000 „ |
| Hamer Pasture Reservoir, 9 acres - - | 58ft. | 72,000,000 „ |

### *Drainage Area.*

Old Works.—500 acres.

New Works.—{ Cowm system, 960 acres.<br>Spring Mill system, 560 acres.

### *Consumption of Water.*

2,000,000 gallons daily.

### *Rainfall from February 1st to March 3rd, 1896.*

| Date. | Rainfall, in inches. | Date. | Rainfall, in inches. |
|---|---|---|---|
| 1896. | | 1896. | |
| February 1 - - | — | February 17 - - | — |
| „ 2 - - | 0·025 | „ 18 - - | — |
| „ 3 - - | — | „ 19 - - | — |
| „ 4 - - | — | „ 20 - - | 0·055 |
| „ 5 - - | 0·020 | „ 21 - - | 0·255 |
| „ 6 - - | 0·020 | „ 22 - - | 0·395 |
| „ 7 - - | 0·035 | „ 23 - | — |
| „ 8 - - | 0·120 | „ 24 - - | — |
| „ 9 - - | 0·140 | „ 25 - - | — |
| „ 10 - - | — | „ 26 - - | — |
| „ 11 - - | — | „ 27 - - | — |
| „ 12 - - | — | „ 28 - - | 0·260 |
| „ 13 - - | 0·255 | „ 29 - | 0·300 |
| „ 14 - | — | March 1 - - | 0·885 |
| „ 15 - - | — | „ 2 - - | 0·200 |
| „ 16 - - | — | „ 3 - - | 0·460 |

### *Notes on the Character of the Gathering Ground.*

The gathering ground is composed of moorland, and nearly the whole of it is covered with grass. The soil is only partially peaty, and is thin and well drained. The underlying rock is chiefly millstone grit. The slopes of the hills are precipitous, and the moorland streams run for the most part on rocky and sandy beds, and for considerable distances before being collected for waterworks purposes. On the higher and flatter portions of the gathering ground, the soil appears to be more peaty and deeper, and it is possible that here the rainfall may have exceptional opportunities for stagnating in the soil. As regards the proportion of spring water to surface-drainage water, it is to be noted that a considerable amount of the total yield of water in ordinary conditions of rainfall appears to have passed through the soil and become altered by its passage through or over the underlying rock. There are several stone and coal quarries on this gathering ground. The water draining from at least one of these workings is of very bad quality, and here the rock (coal) is rich in iron pyrites. It is possible that iron pyrites may be present in the rock elsewhere on the gathering ground, and that water equally bad in quality may drain from such areas.

Comparing the different systems of waterworks supply, the following points are to be noted. There appears to be less peat on the gathering ground of the Spring Mill system than on the areas drained by the Cowm system, or the old works. Nowhere, however, is the peat as abundant as might be expected in the case of a moorland gathering ground. The drainage area of the old works perhaps offers the greatest opportunity for stagnation of the rainfall in the soil. Cowm and Prickshaw Brooks, the main sources of supply to the new works, are of the nature of mountain streams, running on rocky and sandy beds, and with a very rapid fall of water from their respective drainage areas.

### *Conditions found to exist on the Gathering Ground on March 3rd*, 1896.

On March 3rd, 1896, the streams on the gathering ground were running fuller than normal. The daily rainfall from February 1st to March 3rd, 1896, is given in an accompanying table.

An alcoholic solution of lacmoid was used to test the reaction of the various waters.

### *Old Works.*

The two small moorland streams entering the upper end of Brownhouse Wham Reservoir were acid in reaction. The water in the catch-water drain, which collects water from a large area of moorland, was also acid. Formerly the drainage from the neighbourhood of a 40-yards coal working entered this supply. This water is now rejected, as it was found to be extremely acid, and to contaminate the supply. Certain interesting facts in connexion with this water, as well as experiments with water filtered through the rock (coal, rich in iron pyrites) obtained from the quarry are detailed elsewhere. The water in Brownhouse Wham Reservoir was acid, and it was also turbid and discoloured. The water in Hamer Pasture Reservoir—no doubt as a result of the lime treatment—was clear and neutral in reaction.

### *New Works.*

*Spring Mill System.*—The main source of supply is from Prickshaw Brook, and this water, as well as the water in Spring Mill Reservoir, was found to be neutral. A small beck entering the west side of the reservoir was acid, and when traced upwards towards its source, divided into two smaller streams, one of which was found to be acid and the other neutral in reaction. The water before and after filtration was neutral.

*Cowm System.*—Cowm Brook and Cowm Reservoir were both acid, but the water after filtration was neutral in reaction.

Samples of water were collected for more detailed examination from Spring Mill, Cowm, Brownhouse Wham, and Hamer Pasture Reservoirs. The result of the examination of these waters is given in an accompanying table. It is to be noted that the water from Spring Mill

Reservoir was practically neutral and free from plumbo-solvent ability, and that the water from Cowm and Brownhouse Wham were acid and acted distinctly on lead. Hamer Pasture Reservoir water was neutral and free from plumbo-solvent ability. As regards the waters tested on the gathering ground, but not submitted to detailed examination, it is to be noted that when a water gives a distinctly acid reaction with lacmoid, it will dissolve lead, but when it gives a neutral reaction, or—at all events—not a distinctly acid reaction with lacmoid, it will not dissolve lead to any appreciable extent under laboratory conditions of experiment.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the observed Characters of the Gathering Ground.*

It is to be noted that the general characters of this gathering ground are not of such a nature as might be expected to yield an acid water. Thus the beds of peat are not extensive either in depth or superficial area; the soil, which supports a luxuriant growth of rough pasture grass, is only partially peaty in character, the proportion of spring water or water not peaty to peaty water is considerable, and but little opportunity exists for stagnation of the rain in the surface soil. It is important, therefore, to inquire somewhat closely into the cause of the acidity of the various waters examined.

*Old Works.*—Here, perhaps, more than anywhere else on the gathering ground, opportunity is afforded to the rainfall of stagnating in the surface soil before being collected for waterworks purposes. Reference has already been made to a very acid water which naturally drains into this supply, but is now rejected. From the result of certain experiments detailed elsewhere, the acidity of this water appears to be due to the oxidation of iron pyrites which is present in large proportion in the rock (imperfect coal). Filtration experiments through rock rich in this substance, and collected from the quarry, yielded striking results. In brief, neutral distilled water after filtration through the rock became extremely acid, and when sufficiently diluted with neutral distilled water dissolved lead to a very marked extent. The following equation may be taken as representing the action :—

$$FeS_2 + H_2O + 7\ 0 = FeSo_4 + H_2\ So_4.$$

It is possible that, notwithstanding the careful selection of water exercised by the waterworks officials, some water which has passed through rock similarly rich in iron pyrites may enter the supply. It is certain that a very small quantity of this acid water would contaminate a large bulk of water.

On most gathering grounds this question does not assume the importance arising in this case, because, as a rule, the strata which might be suspected to contain iron pyrites crop out lower down than the lowest level of "intake" for waterworks purposes.

### *New Works.*

*Spring Mill System.*—With the exception of the small moorland stream entering the west side of the reservoir the water was all neutral. The explanation seems to be that the conditions already alluded to, which favour a neutral state of water draining from moorland, are here at their best. Thus, among other things, there appears to be a large proportion of spring water and not much peaty water; the slope of the hills draining water to Prickshaw Brook are precipitous, the water in Prickshaw Brook runs for a considerable distance along a rocky and sandy bed, &c. As regards the small moorland stream which, when traced upwards toward its source was found to divide into two smaller streams, the one neutral and the other acid, it is to be noted that the latter contained more peaty water than the former, and drained land where greater opportunity existed for stagnation of the water in the soil.

The fact of the water in the reservoir being neutral points to the probability of Prickshaw Brook having, not only on March 3rd, but always, a similar reaction.

*Cowm System.*—Here the water in Cowm Brook and Cowm Reservoir was acid, and although Cowm Brook drains moorland having less of the conditions favouring a neutral state of the water draining from it than existed in the case of Prickshaw stream, yet the characters of its drainage area do not appear to be such as might be expected to yield a distinctly acid water. Possibly, as was suspected in the case of the old works, some water reaches this supply which has become contaminated by contact with rock rich in iron pyrites. The acidity of the water in the reservoir does not necessarily imply that Cowm Brook is always acid; it may be that in time of drought it is neutral, and in flood time more acid than the body of water in Cowm Reservoir.

In conclusion, it is to be noted that watercourses are not provided for dealing with storm water. It is probable that the quality, as regards acidity and plumbo-solvent ability, of the water in Brownhouse Wham and Cowm Reservoirs might be improved by the exclusion of flood water.

### ROCHDALE CORPORATION WATERWORKS.

TABLE 20.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Acidity. | | Action on Lead (Results stated as Parts per 100,000). The action on Lead was tested by means of upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Reaction with Lacmoid. | In Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | March 4th, 1896, water from Spring Mill Reservoir. | ? Faint trace acid. | ? Faint trace acid. | ? Faint traces. | | | | | |
| 2 | March 4th, 1896, water from Cowm Reservoir. | Acid | 0·30 | 0·1 | 0·3 | 0·4 | 0·5 | 0·5 | 0·36 |
| 3 | March 4th, 1896, water from Brownhouse Wham Reservoir. | Acid | 0·36 | 0·2 | 0·4 | 0·5 | 0·5 | 0·6 | 0·44 |
| 4 | March 4th, 1896, water from Hamer Pasture Reservoir. | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |

## Survey No. 21.

## SHEFFIELD CORPORATION WATERWORK

### SOURCE OF THE WATER SUPPLY AND GENERAL DESCRIP THE WATERWORKS.

The water supply of the Sheffield Corporation is der
moorland gathering grounds, situate some five to eight mil
Sheffield. The high level supply is obtained from gatheri
at Redmires, and the low level from gathering grounds
immediately to the north of the high level supply in the upla
of the Rivers Rivelin and Loxley, both tributaries of the Rive

*High Level Supply.*—There are three reservoirs on this
ground, and the course taken by the water is as follows
Redmires Reservoir is supplied with water from Oaken Cloug
which extends for a distance of about two miles, drains a lar
moorland, and begins in a mountain stream known as Oake
*A catchwater extends along the west bank of the reserv
connected with the Oaken Clough Conduit at the north,
Fairthorn Clough at the south end of the reservoir. It recei
from a number of small streams draining from moorland. T
from Oaken Clough Conduit, Fairthorn Clough, and the catch
the only sources of supply to this reservoir. Middle Redmires
is supplied with water from Upper Redmires. *A small c
extends along the south-west side of the reservoir, and collec
most part storm water draining from the adjacent moorland.
Redmires Reservoir is supplied with water from Middle Redn.
small mountain stream, known as Wyming Brook, enters the s
of the reservoir, and it drains moorland near White Stones.

The gradual passage of the water from Upper to Middle, a
Middle to Lower Redmires, allows the peaty matter to subs
purifies the water to a considerable extent.

From Lower Redmires the water can be sent down the
Brook to Rivelin, or carried to a chamber where it is treat
carbonate of lime (whiting), by means of an ingenious arrangemen
works automatically, and which thoroughly mixes the water a
together. Rather more lime is added to the water than it is ca
dissolving, about two grains to the gallon. From the chamb
treated water carrying an excess of lime in suspension, is convey
distance of several miles in a channel made for the purpose to H
service Reservoir, for distribution in the borough. In its passag
this channel the water becomes less and less milky, until at last
reaching Hadfield Reservoir all the lime is either in solution
deposited.

*Low Level Supply.*—This supply is best described unde
headings.

*Rivelin System.*—There are two reservoirs on this gathering g
Upper and Lower Rivelin. The Upper Reservoir is supplied wit
from Rivelin Brook, which drains a very large area of moorland.
Lower Reservoir is supplied chiefly from the upper, and it also rec
certain amount of water from Wyming Brook. The water fr
Rivelin Reservoirs is piped to a depositing pond where it mixes w
water from Allan Sike, and is given out as compensation water.
water from the tunnel from Loxley Watershed, can be taken i

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* The waterworks engineer supplies a note to the effect that these catc
were made under circumstances which no longer obtain. 1897.

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depositing pond, or with that from the Upper and Lower Reservoirs into the gauge basin, from thence it is conveyed in a conduit to Crook's Moor service reservoirs for distribution in the borough. The passage of the water from Upper to Lower Rivelin, and from Lower Rivelin to the depositing pond allows of a considerable amount of subsidence of suspended matter.

*Loxley System.*—Their are four reservoirs on this gathering ground, known as Strines, Dale Dike, Agden, and Damflask Reservoirs. Strines, Dale Dike, and Agden waters are used for domestic use, and Damflask water for compensation. The course of the water is from Strines to Dale Dike, and from Dale Dike to Damflask. The water from Dale Dike is joined by the water from Agden before entering Damflask Reservoir. From Damflask, the water is supplied for compensation only. The water from Strines, Dale Dike, and Agden Reservoirs is also carried by means of a conduit and tunnel to the depositing pond at Rivelin. The chief source of supply to Strines Reservoir is from Bents Clough, Pears House Clough, and Strines Brook. Agden Reservoir is supplied with water from Agden water and Rocher Brook. Damflask receives the water from Ughill Brook, as well as the overflow waters from Dale Dike and Agden. Dale Dike, as has been already indicated, receives its supply from Strines Reservoir and its own gathering ground.

The water from this (low level) system of water supply is not treated in any way.

No special arrangements appear to exist, in connection with the high and low level systems, for excluding storm water from the waterworks. Mr. Marsh, the waterworks engineer, however, remarks that the waters from different sources can, if desired, be taken or left at the discretion of the waterworks manager, and he takes occasion to note at the same time the purpose for which, in his view, the storage reservoirs have been constructed :—"The purpose for which properly designed storage "reservoirs are constructed, viz., to store water gathered in times of "flood in order to distribute it over periods of drought; otherwise "such costly works would be unnecessary, and it would be sufficient to "pipe the streams to the localities requiring a supply." It is to be regretted that the above is only too true in the case of many *moorland* water-supplies; that not only is the "dry weather flow," which is usually neutral, and free from action on lead, taken for waterworks purposes, but that "storm water," which is usually peaty, acid, and possessed of plumbo-solvent ability, is commonly utilised as well. The disadvantage of this practice may be illustrated, thus :—If the water from the supply streams to the Redmires Reservoirs were allowed to enter the waterworks only under ordinary conditions of rainfall, the water stored in these reservoirs would, in all probability, remain neutral, instead of being acid—as was found to be the case on June 14th, 1895.

The following notes on Sheffield Corporation Waterworks are of interest :—

*Rainfall.*

| | |
|---|---|
| Average yearly rainfall in Sheffield - | These data could not be obtained. |
| " " " on gathering ground - | |
| " " " on the high level - | |
| " " " on gathering ground - | |
| " " " on the low level - | |

*Capacity, &c., of Storage Reservoirs.*

| Name. | Area, in Acres. | Top Water Level, in Feet. | Depth, in Feet. | Capacity, in Gallons. |
|---|---|---|---|---|
| Upper Redmires - - | 56 | About 1,150 | 43 | 343,000,000 |
| Middle „ - - - | 48 | -- | 36 | 187,500,000 |
| Lower „ - - | 28¾ | — | 29 | 139,500,000 |
| Upper Rivelin - - - | 10¾ | About 700 | 31½ | 48,500,000 |
| Lower „ - - | 29½ | — | 50½ | 175,000,000 |
| Depositing pond - - - | 4 | — | 15 | 8,000,000 |
| Agden - - - - | 62¾ | About 650 | 90 | 629,000,000 |
| Strines - - - . - | 54¾ | „ 800 | 67 | 513,000,000 |
| Dale Dike - - - | 62 | „ 700 | 67 | 486,000,000 |
| Damflask - - - | 115½ | „ 500 | 85 | 1,158,000,000 |

*Drainage Areas.*

| | |
|---|---|
| Redmires, Upper<br>„ Middle<br>„ Lower | 2,108 acres. |
| Rivelin, Upper -<br>„ Lower -<br>Depositing pond - | 2,870 „ |
| Agden - - | 2,999 „ |
| Strines - - | 2,890 „ |
| Dale Dike - - | 1,089 „ |
| Damflask - - | 3,747 „ |
| | 15,703 „ Total drainage area of existing works. |

*Consumption of water.*—About 7½ million gallons daily.

*Daily Rainfall on High and Low Level Gathering Grounds from 14th May* 1895 *to 14th June* 1895, *inclusive, and Weekly Rainfall over the same period at Dale Dike Reservoir*:—

| Date. | Redmires. | Rivelin. | Date. | Redmires. | Rivelin. |
|---|---|---|---|---|---|
| 1895. | Inches. | Inches. | 1895. | Inches. | Inches. |
| May 14th - - | — | — | May 30th - - | ·090 | ·110 |
| „ 15th - - | — | — | „ 31st - | — | — |
| „ 16th - - | — | — | June 1st - - | ·180 | ·170 |
| „ 17th - - | ·130 | ·115 | „ 2nd - | ·070 | ·160 |
| „ 18th - - | — | — | „ 3rd - - | ·005 | — |
| „ 19th - - | ·005 | — | „ 4th - | ·015 | ·005 |
| „ 20th - - | ·040 | ·040 | „ 5th - - | — | — |
| „ 21st - - | ·065 | ·080 | „ 6th - | — | — |
| „ 22nd - - | — | — | „ 7th - - | — | — |
| „ 23rd - - | ·005 | ·005 | „ 8th - | — | — |
| „ 24th - - | ·160 | ·415 | „ 9th - - | — | — |
| „ 25th - - | ·120 | ·050 | „ 10th - | — | — |
| „ 26th - - | — | — | „ 11th - - | ·160 | ·140 |
| „ 27th - - | — | — | „ 12th - | ·005 | ·055 |
| „ 28th - - | — | — | „ 13th - - | — | — |
| „ 29th - - | — | — | „ 14th - | — | ·010 |

### *Dale Dike Reservoir.*

For the year 1895.

| | | |
|---|---|---|
| Week ending May 18th | - - | ·16 inches. |
| " " 25th | - - - | ·25 " |
| " June 1st | - - | ·12 " |
| " " 8th | - - - | ·24 " |
| " " 15th | - - | ·17 " |

### *Notes on the Characters of the Gathering Grounds.*

*High Level Supply.*—The gathering ground is composed entirely of moorland. Peat is abundant everywhere on the collecting ground, and it varies in thickness from 1 to 6 feet, or even more in certain places. The vegetation consists chiefly of heather and moss, and in a few places rough pasture grass is to be found. Shale and millstone grit underlie the surface soil. The slopes of the hills near the reservoirs are fairly steep, but higher up on the collecting ground the ground is much flatter, and here the peat is most abundant and attains to its greatest thickness.

The drainage from the soil in the neighbourhood of the reservoirs is more or less satisfactory, but on the upper portions of the drainage area the conditions are much less favourable, and here the water stagnates in the peat, forming peat and bog holes, and marshy places. The dry weather flow in the streams is small in amount, there being but few hillside springs. On the other hand, the flow during storms is very great, and consists chiefly of peaty water derived from surface drainage.

*Low Level Supply.*—The gathering ground of the low level supply differs in certain respects from the high level, but the difference is one of degree rather than of kind. Thus the peat is far less abundant superficially and in depth, the drainage from the soil is more rapid, and there are but few places where the water can stagnate in peaty soil; the slopes of the hills are more abrupt, and the water drains more rapidly into the waterworks, and the spring water is greater, and the peaty water less in amount in the low as compared with the high level supply. It is to be noted also that the streams on this collecting ground run on rocky and sandy beds for a considerable distance before being collected for waterworks purposes, and, in many instances, they are bordered by plantations of trees. Lastly, the soil in many places contains very little peat, and there are large portions of the gathering ground covered with the growth of grass.

### *Conditions found to exist on the Gathering Ground on the* 14*th and* 15*th June* 1895.

It is to be noted from the accompanying table that the rainfall previous to the above dates was much below the average. The streams, in consequence, contained chiefly spring water and very little water derived from surface drainage.

Lacmoid was used to test the reaction of the various waters. Judging by laboratory experiments a water which gives a neutral reaction with lacmoid has little or no plumbo-solvent ability, but a water which gives an acid reaction will dissolve lead to an extent depending on the amount of the acidity.

*High Level Supply.*—The water in Upper, Middle, and Lower Redmires Reservoirs was tested at various points, and was found to be distinctly acid. Oaken Clough Conduit contained neutral water. The water in Fairthorn Clough was neutral, but on being traced upwards, one of its chief tributaries was found to be decidedly acid. The waters in the catchwaters in connexion with Upper and Middle Redmires was neutral, and the small stream supplying Lower Redmires had a similar reaction. The Redmires water was tested just before entering the treatment chamber and it was found to be distinctly acid. The treated water was tested after it had run for some considerable distance along the channel leading to Hadfield Reservoir, and it was neutral in reaction. The water in Hadfield was neutral and of a clear blue colour, whereas the water from Redmires before entering the treatment chamber was of a dirty peaty colour.

*Low Level Supply.—Rivelin System.* Upper and Lower Rivelin Reservoirs contained neutral water. Rivelin Brook, Wyming Brook, and Allansyke water were all neutral. The water issuing from the tunnel from the Loxley watershed had a similar reaction.

*Loxley System.*—All the waters that were tested on this gathering ground gave a neutral reaction with lacmoid, viz.:—Strines, Dale Dike, Agden, and Damflask Reservoirs, Bents, and Pears House Cloughs, Strines Brook, Agden water, Ughill Brook, and Rocher water.

Samples of water were collected for special examination from the following sources:—Strines Reservoir at outlet, Loxley water at tunnel exit, Agden Reservoir, Redmires water immediately before "treatment" with lime, Hadfield Resevoir after treatment with lime, and Upper Redmires Reservoir. Previously, samples of water had been obtained from the high and low services, as supplied to the consumers in Sheffield. The results of the examination of these waters, which are shown in an accompanying table, may be briefly described as follows:—All the waters were neutral and free from action on lead with the exception of the Redmires water. It is to be noted that the water from Upper Redmires Reservoir was more acid and acted more strongly on lead than (practically) the same water after it had passed through Middle and Lower Redmires Reservoirs. Water entering Upper Redmires would probably take some weeks or even months to reach the outlet at Lower Redmires, and it is possible that the mere storage of the water, apart from any other influence, may have reduced the amount of the acidity. This would correspond with certain laboratory experiments in which, when acid moorland waters were kept for some time in unstoppered bottles, a decrease in acidity was usually noticed.

As regards the hardness of the various waters, it is to be noted that after treatment with lime the Redmires water was materially hardened. Like most water supplies obtained from moorland sources, all the waters were very soft.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the Observed Characters of the Gathering Grounds.*

*High Level Supply.*—The question naturally arises as to why Redmires was acid when all the inlet streams to the reservoirs were neutral. The acidity of the water in the Redmires Reservoirs is only to be expected from the characters of the drainage area which have been already described. The neutral condition of the "inlet" streams on the 14th June seems to be traceable to the fact that, prior to this date, the rainfall was much below the average, and the water draining into the waterworks was chiefly from springs and only to an inconsiderable extent from the drainage of peaty soil. From the nature of the gathering ground it is in the highest degree probable that Fairthorn Clough, Oaken Clough Conduit, and the catchwater drains normally supply the Redmires Reservoirs with acid water. At Dr. Houston's suggestion Mr. Marsh—then the assistant waterworks engineer—kindly tested Oaken Clough under ordinary conditions of rainfall and with the result that the water was found to be acid.

It may be assumed, with a great amount of probability, that the Redmires Reservoirs are supplied with neutral water (chiefly from springs) during the dry weather flow of the supply streams, and with acid water (chiefly from the surface drainage of peat) during storms, and even, perhaps, during ordinary conditions of the rainfall. It has already been shown that the acid and peat-coloured Redmires water after treatment with lime was changed into a neutral water of a clear blue colour.

*Low Level Supply.*—The marked points of difference between the characters of the high, as compared with the low level gathering grounds might lead to the supposition that the water draining from the collecting grounds would likewise show some qualitative difference. And this was found to be the case, for whereas the high level supply yielded an acid water, the low level supply was found to be neutral. The neutral condition of the low level supply appears to be no chance condition dependent on drought, for the reservoirs, without exception, contained neutral water, and from the characters of the drainage areas it is unlikely that the supply streams are ever acid even under extraordinary conditions of the rainfall.

Thus, it appears that the chemical results correspond very closely with the observed characters of the gathering grounds.

SHEFFIELD CORPORATION WATERWORKS.

*Table 21.—Chemical Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ parts per 100,000). | Action on Lead (Results stated as parts per 100,000). The action on Lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average. |
| 1 | May 31st, 1895. "High Level" supply, from main in Sheffield. | Neutral | Neutral | 6·3 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 2 | May 31st, 1895. "Low Level" supply, from main in Sheffield. | Neutral | Neutral | 4·8 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 3 | June 15th, 1895. Loxley water at tunnel exit, near depositing pond. | Neutral | Neutral | 3·64 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 4 | June 15th, 1895. "Outflow" water from Strines Reservoir. | Neutral | Neutral | 2·94 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 5 | June 15th, 1895. Agden Reservoir water. | Neutral | Neutral | 3·78 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 6 | June 15th, 1895. Redmires water immediately before "treatment" with lime. | Acid | 0·24 | 3·92 | 0·0 | 0·1 | 0·2 | 0·2 | 0·3 | 0·16 |
| 7 | June 15th, 1895. Redmires water after "treatment" with lime. Sample taken from Hadfield Reservoir. | Neutral | Neutral | 6·72 | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 8 | June 15th, 1895. Upper Redmires Reservoir water. | Acid | 0·36 | 3·64 | 0·1 | 0·3 | 0·4 | 0·4 | 0·5 | 0·34 |

## Survey No. 22.

### SHIPLEY (ELDWICK) WATERWORKS.

### Source of the Water Supply and General Description of the Waterworks.

The water supply of Shipley is obtained from Rombald's Moor, about four miles to the north-east of Shipley.

The water draining from Rombald's Moor is stored in Graincliffe and Eldwick Reservoirs. The water from Graincliffe is conveyed to sand filter beds, and from thence by the high level conduit direct to the high parts of the town of Shipley. The water from Eldwick is carried by the low level conduit to the service reservoirs near Baildon, and from thence to the low levels of the town. It is not filtered before delivery. More in detail, the arrangements for the collection of water are as follows:—

Graincliffe Reservoir is situated at a height of 845 feet above sea level, and is supplied with water from the following sources: Graincliffe stream drains a large area of moorland, and enters the reservoir at its north-western extremity. Blackdyke stream drains a considerable tract of moorland to the north of the reservoir. This water when it reaches the reservoir is carried in a bye-channel to the north-east angle of the reservoir. Here it mixes with the water from Weecher Flat and can be turned into the reservoir or carried along the overflow channel to the lower reservoir. Weecher stream drains peat land known as Weecher Flat, and the water, after mixing with Blackdyke, can be turned into the reservoir or carried down the overflow channel to the bed of Eldwick Beck, which leads to Eldwick Reservoir. The "outlet" water from Graincliffe Reservoir is piped to the filter beds, and it can also be sent down Eldwick Beck to the lower reservoir. The Graincliffe drainage area all lies immediately to the north of the reservoir, and Graincliffe collects the water draining from the west side, Weecher the water from the east, and Blackdyke the water from the middle portion of the gathering ground.

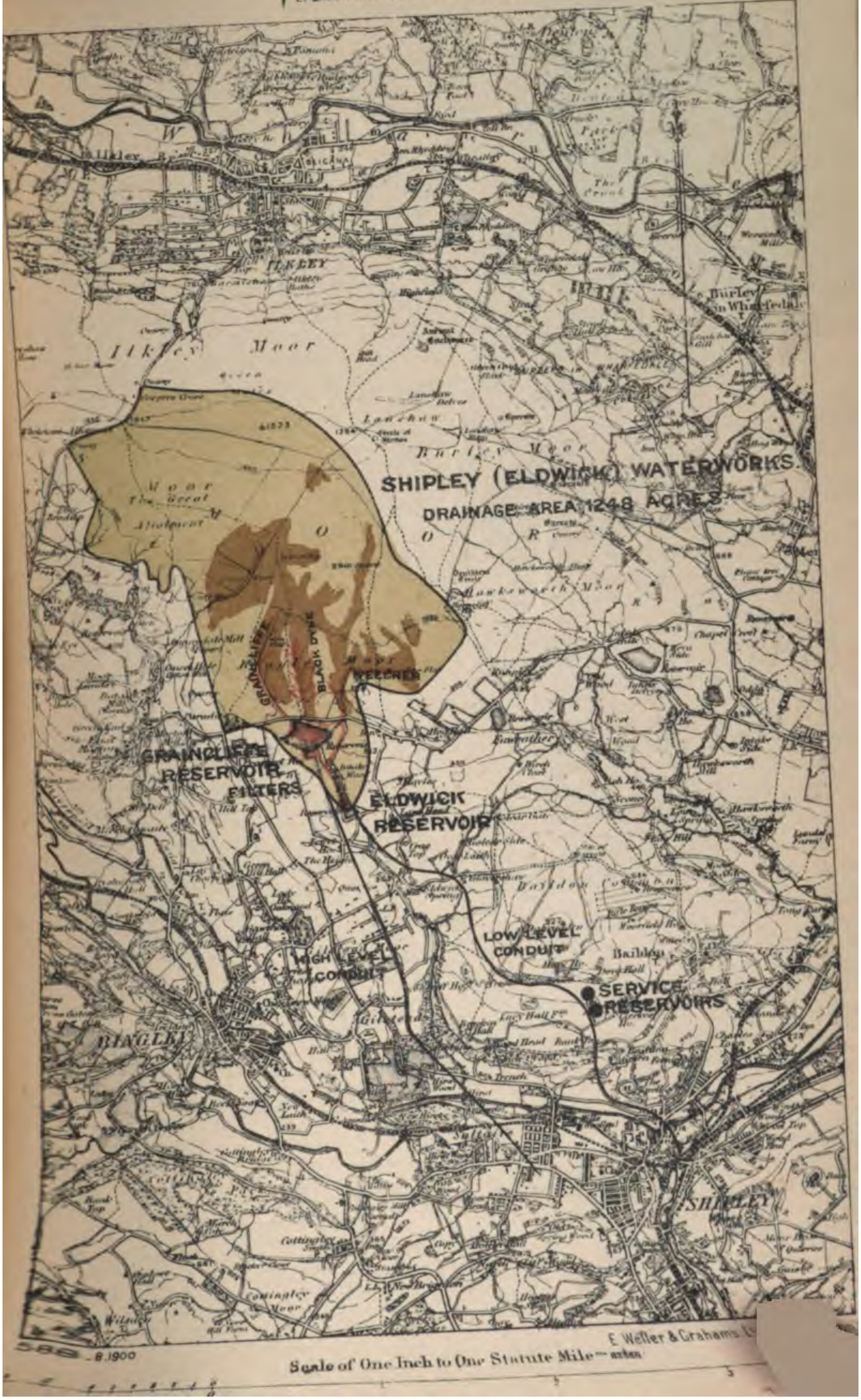
Eldwick Reservoir is situated at a height of 689 feet above sea level and is supplied with water from Eldwick Beck. Eldwick Beck can receive the water from Weecher or the mixed water from Weecher and Blackdyke, or the overflow from Graincliffe Reservoir, or the outlet water from the higher reservoir.

As has been already explained, the Graincliffe water, after having been submitted to sand filtration, is carried direct to the high levels of the town, whereas the Eldwick water is carried without filtration to the service reservoirs for the supply of the low-lying parts of Shipley.

For some three or four years prior to 1897 whiting has been used to neutralise the acidity of the high level service. Before May 1895 the council undertook the formation of bye-channels, so that after a period of fine weather the caretaker can divert the first flush of foul water, and prevent it from entering the waterworks. The waterworks authorities believe that this has materially reduced the amount of acid water gaining access to the waterworks.

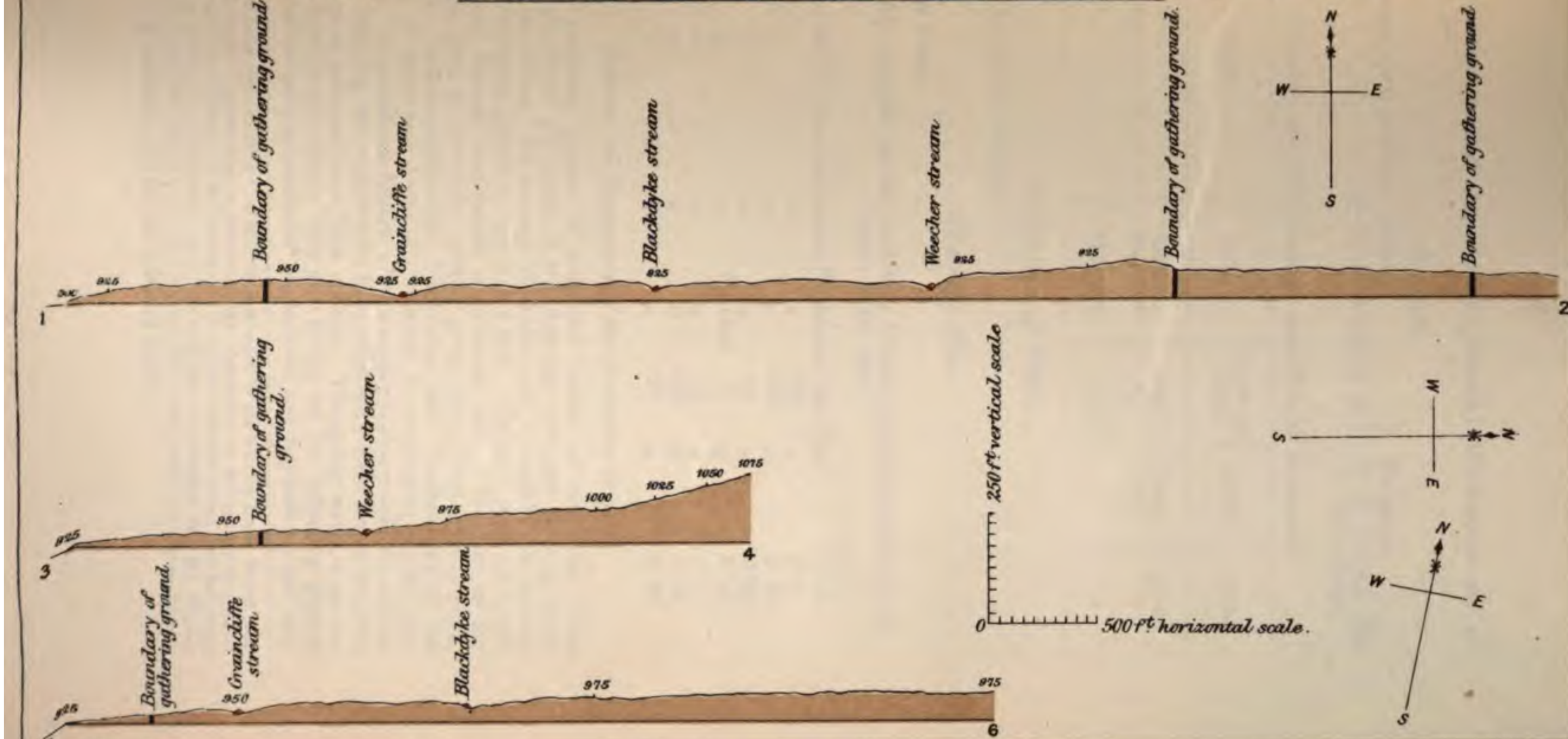
# SHIPLEY (ELDWICK) WATERWORKS.

*(October 25th 1894)*



[illegible] & Grahams. Lit. Litho London.

## SHIPLEY (ELDWICK) WATER WORKS. *Plan showing sectional view of the gathering ground along certain lines marked 1, 2; 3, 4; 5, 6; on accompanying 6" ordnance map. The line 1, 2; runs due west & east, the line 3, 4; due south & north & the line 5, 6; nearly due west & east.*



E. Weller & Grahams. Ltd Litho. London.

588.6.1900.

The following notes on Shipley (Eldwick) Waterworks are of interest:—

### *Rainfall.*

| | |
|---|---|
| Average yearly rainfall in Shipley - | No gauge. |
| „ „ „ on the gathering ground | 34·35 average for three years. |

### *Capacity, &c., of Graincliffe and Eldwick Reservoirs.*

| Name. | Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|---|
| | Gallons. | Feet. | Feet. | Acres. |
| Graincliffe - - - | 95,531,000 | 845 | 45 | 17 |
| Eldwick - - - - | 25,000,000 | 689 | 33 | 5 |

### *Consumption of Water.*

750,000 gallons per day.

### *Drainage Area.*

1,248 acres.

### *Weekly Rainfall on the Gathering Ground from September 1st to October 27th, 1894.*

| | Inches. |
|---|---|
| Rainfall for the week ended September 8th, 1894 - | 0·55 |
| „ „ „ „ 15 „ - | 0·01 |
| „ „ „ „ 22 „ - | 0·38 |
| „ „ „ „ 29 „ - | 0·00 |
| „ „ „ October 6 „ - | 0·16 |
| „ „ „ „ 13 „ - | 0·54 |
| „ „ „ „ 20 „ - | 0·34 |
| „ „ „ „ 27 „ - | 3·49 |

### *Notes on the Characters of the Gathering Ground.*

The gathering ground is composed entirely of moorland. Peat covers practically the whole of the drainage area, and varies in depth from 1 to 10 feet. Its average thickness over a considerable portion of the collecting ground is from 2 to 4 feet. The peat rests on a stiff marl, and the rock underneath is millstone grit. The whole of the drainage area is nearly flat, with a gentle slope from north to south, and the feeders—Graincliffe, Blackdyke, and Weecher—are of the nature of large peat drains fed laterally by numberless smaller peat drains. A remarkable feature of this supply is that practically all the water reaching the waterworks from Rombald's Moor comes from the drainage of peat, and none from springs. The spring water crops out lower down in the valley. The rain falling on the collecting ground saturates the peat, accumulates[*] in hollows and depressions, and only slowly escapes by lateral percolation, the marl hindering the water from escaping readily in a downward direction. It follows from the above that a large portion of the drainage area is of the nature of a huge flat peat sponge lying on a more or less impermeable bed. This sponge holds an enormous body of water in its interstices. When a flood comes the water which has lain in contact with the peat for days, or weeks, or months, is washed into the waterworks, and fresh water takes its place. There is very little pasture grass on this collecting ground, in many places the soil is bare of vegetation, black peat alone showing on the surface, and in other places there is an abundant growth of heather and bog moss. It is only right to state that the waterworks authorities have endeavoured to improve these unfavourable conditions. Thus rough limestone filters have been placed on the course of Graincliffe stream, and ditches have been cut in numerous places to facilitate the passage of the water into the main streams and to prevent the rain from stagnating in the peat, and generally the attempt has been made to get the water in bulk into the reservoirs as soon as possible.

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[*] It is only right to state that Mr. Rhodes, clerk to the Shipley Local Board, who has had ample opportunities of observing the characters of the gathering ground under varying conditions of the weather, is of opinion that the water does not lodge as above stated, except in isolated cases. It may here be remarked that Mr. Rhodes and the waterworks officials have done the utmost in their power towards facilitating the work in connexion with the lead poisoning inquiry.

It is to be noted that most of the feeders run on clay bottoms. Some authorities have held that the acidity of moorland waters disappears in process of time owing to the feeders gradually washing away the surface soil and eventually running on clay and rocky beds. It is evident that the above can only be true to a very limited extent in the case of this water supply.

In nearly all the feeders the banks are of peat, and overhang, and in consequence large quantities of peat are washed into and along the beds of the streams, and finally into the reservoirs.

### *Conditions found to exist on the Gathering Ground on October* 25, 1894.

The rainfall prior to the above date is given in an accompanying table. It is to be noted that, owing to the preceding rains, the streams were running fuller than normal.

Lacmoid was used to test the reaction of the various waters, and it is to be noted that under laboratory conditions of experiment, when a water gives a neutral reaction with this indicator, it will dissolve lead to an extent depending on the amount of the acidity. The water in Graincliffe and Eldwick Reservoirs was found to be distinctly acid. The three streams draining Rombald's Moor, viz., Graincliffe, Blackdyke, and Weecher, were very acid. One of these—Weecher—was traced for a considerable distance up its course, and the water was tested at many points, and always found to be acid. Graincliffe and Blackdyke were followed all the way up to their source in peaty and boggy land. As regards Graincliffe, one very small ferruginous stream was found entering it near its source. The rest of its feeders, seven in number, drained peaty, boggy, and marshy land, and they all yielded a highly acid water. The source of the supply to Blackdyke was also carefully investigated. Like Graincliffe, the water was acid along its entire course, and only one minute stream could be found supplying with neutral water. Eleven peat drains supplied it with acid water on the west side, and the same number of feeders entered the east side, all having a similar reaction. Besides the above, a large number of tests were made of the water stagnating in peaty, boggy, and marshy places, and the water dripping from the peat bordering on and over-hanging the feeders. In all cases the water was found to have an acid reaction, and the degree of acidity appeared to be associated with the amount of contamination with peaty water.

Samples of water were collected for more detailed examination from the following sources: Graincliffe, Blackdyke, and Weecher streams, and Eldwick Reservoir. The results are given in an accompanying table, and may be briefly summarised as follows: All the waters were very acid, and acted strongly on lead, the reservoir water being least conspicuous in these respects. The waters were "soft," but not so "soft" as might be expected, considering their source. Experiments show that the more acid moorland waters are, the "harder" they are apt to be, and that neutralisation with sodium carbonate distinctly "softens" them.

Samples of water were obtained at regular intervals and over a considerable space of time from Eldwick Reservoir. The results are shown in a separate table, and will be discussed elsewhere. It may be stated here, however, that the results showed that the water was invariably acid, and possessed of great plumbo-solvent ability.

### *Remarks on the Results yielded by the Chemical Examination of the Waters in reference to the Observed Characters of the Gathering Ground.*

It is to be noted that the water in the storage reservoirs (Graincliffe and Eldwick), and in the feeders supplying these reservoirs (Graincliffe, Blackdyke, and Weecher), was found to be very acid. The explanation is to be sought for in the characters of the watershed, which have been already described. Thus it has been shown that peat is very abundant superficially and in depth, that there is very little spring water and a large amount of peaty water, that the rain saturates the soil and lies stagnant in peaty and mossy pools and in marshy places, and that the drainage from the soil is very slow, &c., &c. The acidity and plumbo-solvent ability of the various waters is not to be regarded as a chance condition, depending on the rainfall prior to the date of visiting the gathering ground. In all probability Graincliffe, Blackdyke, and Weecher always contain an acid water, because, unlike most moorland streams, there is practically no "dry weather flow" from hillside springs. It is almost certain that Graincliffe Reservoir is always acid, because samples obtained periodically from Eldwick Reservoir, which is fed from the same drainage area, were always found to be very acid.

It is important to note that not only were the main streams—Graincliffe, Blackdyke, and Weecher—acid, but that all the tributary feeders that were tested had a similar reaction, with the exception of an inconsiderable amount of water entering Graincliffe and Blackdyke. These tributary feeders—29 in number—were in many cases drains cut in the peat to carry away the rain water which saturated the soil and accumulated in hollows and depressions, forming peat bogs and swamps.

The results of the inspection of the gathering ground, together with the chemical tests, seem to show that acidity is to be associated with drainage from peat, and that the degree of acidity is to be associated with the amount of contamination with peaty water.

## SHIPLEY (ELDWICK) WATERWORKS.

### TABLE 22.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 c.c. of the Water. | Hardness ($CaCO_3$ parts per 100,000). | Action on Lead (Results stated as Par per 100,000). The action on Lead was tes by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 min per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Ave |
| 1 | October 25th, 1894. Graincliffe stream, one of the main feeders to Graincliffe Reservoir. | Acid | 1·26 | 5·6 | 2·0 | 5·0 | 5·0 | 5·0 | 5·5 | 4 |
| 2 | October 25th, 1894. Weecher stream, one of the main feeders to Graincliffe Reservoir, or to Eldwick Reservoir. | Acid | 1·08 | 4·9 | 2·0 | 4·5 | 5·0 | 5·0 | 4·5 | 4 |
| 3 | October 25th, 1894. Blackdyke stream, one of main feeder to Graincliffe Reservoir, or to Eldwick Reservoir. | Acid | 1·20 | 5·2 | 3·0 | 5·0 | 5·0 | 5·0 | 5·5 | 4 |
| 4 | October 25th, 1894. Graincliffe Reservoir water near "outlet." | Acid | 0·96 | 5·32 | 1·5 | 4·5 | 4·0 | 3·5 | 4·0 | 3 |

## Survey No. 23.

### WAKEFIELD CORPORATION WATERWORKS.

### Source of the Water Supply and General Description of the Waterworks. (*For map, see Survey* 13.)

The water supply of the Wakefield Corporation has, since 1888, been obtained from moorland gathering grounds situate at Rishworth, some 26 miles west-south-west from Wakefield.

A catchwater conduit (Mossmoor Catchwater), nearly 5 miles in length, collects, at its upper end, the water from a moorland stream—Spa Clough. Along its course this catchwater receives the drainage from a very large tract of moorland. All the water draining from the hill slopes on the south-east side finds its way into the catchwater, and the amount of water thus collected for waterworks purposes is very great. In certain instances the water draining from the moors is led into a basin so constructed as to keep back the peat. This arrangement is used in connexion with most of the large streams and those which contain most surface water. Notwithstanding these precautions, which are none the less of considerable value, a large quantity of peat finds its way into the waterworks in storm time.

In many cases rough drains are cut in the soil to facilitate the rapid passage of surface water into consumption and to prevent water from stagnating in boggy and marshy places. Mossmoor Catchwater discharges its water (a variable mixture of spring water and surface peaty water) into Ringstone Reservoir, and this is practically the only source of supply to Ringstone, except in flood time, when an inconsiderable amount of surface water enters the waterworks from moorland along one side of the reservoir.

Ringstone is a large reservoir, and a considerable amount of sedimentation takes place before the water is carried on to Ardsley, where it is "treated" and stored before its final transmission to the consumers in Wakefield.

At Ardsley, close to the point where the "inlet" water from Ringstone enters the reservoir, there are a series of large barrels connected together by pipes, in which a concentrated soda mixture (about 1 lb. sodium carbonate to every gallon of water) is made.

Five hundred gallons of this strong solution of soda are allowed to mix with every million gallons of Ringstone water entering Ardsley Reservoir.

After storage in Ardsley Reservoir, the "treated" water is conveyed without any process of filtration to Wakefield.

The following notes on Wakefield Corporation Waterworks are of interest:—

*Rainfall.*

| | inches. |
|---|---|
| Average yearly rainfall in Wakefield - - - | 26·05 |
| " " " on gathering ground - - - | 45·38 |

*Capacity, etc., of Reservoirs.*

| — | Capacity. | Top Water Level. | Depth. | Area. |
|---|---|---|---|---|
| | | Ft. | Ft. in. | Acres. |
| Ringstone Reservoir | 244,000,000 | 994 above O. D. | 45 6 | 49 |
| Ardsley " - | 320,000,000 | 383 " " | 63 0 | 59 |

*Drainage Area.*—1992 acres.

### *Consumption of Water.*

**2,000,000 gallons per diem for Wakefield and out-districts.**

**1,133,000 „ „ „ compensation.**

***Rainfall*** **(daily) on *gathering ground* from September 3rd to October 3rd, 1894 (inclusive).**

### WAKEFIELD WATERWORKS.

***Daily Rainfall on Gathering Ground September 3rd to October 3rd,*** **1894.**

| 1894. | Ringstone Gauge. | Stott Hall Gauge. | Great Waldron Edge Gauge. | 1894. | Ringstone Gauge. | Stott Hall Gauge. | Great Waldron Edge Gauge. |
|---|---|---|---|---|---|---|---|
| | In. | In. | In. | | In. | In. | In. |
| Sept. 3 - | ·02 | ·02 | ·01 | Sept. 19 - | — | — | — |
| „ 4 - | — | — | — | „ 20 - | ·24 | ·37 | ·34 |
| „ 5 - | ·05 | ·04 | ·02 | „ 21 - | ·13 | ·12 | ·14 |
| „ 6 - | ·08 | ·19 | ·16 | „ 22 - | — | — | — |
| „ 7 - | — | — | — | „ 23 - | — | — | — |
| „ 8 - | — | — | — | „ 24 - | — | — | — |
| „ 9 - | ·04 | — | — | „ 25 - | — | — | — |
| „ 10 - | — | — | — | „ 26 - | ·07 | ·09 | ·08 |
| „ 11 - | — | — | — | „ 27 - | — | — | — |
| „ 12 - | — | — | — | „ 28 - | — | — | — |
| „ 13 - | — | — | — | „ 29 - | — | — | — |
| „ 14 - | — | — | — | „ 30 - | — | — | — |
| „ 15 - | — | — | — | Oct. 1 - | — | — | — |
| „ 16 - | — | — | — | „ 2 - | — | — | — |
| „ 17 - | — | — | — | „ 3 - | — | — | — |
| „ 18 - | ·02 | ·04 | ·02 | | | | |

### *Notes on the Character of the Gathering Ground.*

The gathering ground is composed of moorland. The vegetation consists partly of coarse pasture grass, but chiefly of heather. The surface soil over nearly the whole of the gathering ground is peaty, and generally it may be said that peat is very abundant, both as regards its superficial extent and also as regards its depth.

The rock underlying the surface soil is chiefly Millstone Grit.

Although the slopes of the hills are fairly abrupt, there are numerous areas on this gathering ground where the rain saturates the soil and stagnates in peaty and marshy places.

There is a considerable proportion of spring water as compared with surface water under ordinary conditions of rainfall, but in storm time the amount of surface peaty water entering the waterworks is very great, and its character is such that the good quality of the spring water is lost in the bad quality of the peaty water.

### *Conditions found to exist on the Gathering Ground on October 3rd,* 1894.

It is to be noted that the conditions were not normal on October 3rd, 1894, as regards the rainfall. Owing to the preceding drought, nearly all the feeders to the catchwater were dried up, and practically the only water entering the waterworks was from the springs.

Ringstone Reservoir was tested at various points, and the water was found to be distinctly acid in reaction.

Mossmoor Catchwater was followed towards its origin for several *miles, and the* water running along its channel and the water draining into it at various points from the catchment area was tested. The water in every case was found to be neutral.

Ardsley Reservoir was visited at a later date, but it is convenient to state here that the water from Ringstone Reservoir was distinctly acid, and the water in Ardsley Reservoir, after treatment with sodium carbonate, was neutral in reaction.

The results of the examination of the waters are given in an accompanying table.

Briefly the analyses of these waters showed the following:—

Ringstone Reservoir water (two samples) was very acid, and acted strongly on lead.

The same remark applies to the "inlet" water (four samples) from Ringstone to Ardsley Reservoir—before "treatment."

The "treated" water (two samples), as supplied to the consumers in Wakefield, was free from acidity and plumbo-solvent ability, as was also the "outlet" water (two samples) from Ardsley Reservoir after "treatment." The water, as noted above, in Mossmoor Catchwater was neutral on October 3rd, 1894, but the water from the same source obtained at a later date, November 7th, 1894, and after heavy rains, was very acid, and had a strong plumbo-solvent action on lead.

It is to be noted that the neutral "treated" water was softer than the acid "untreated" water.

### *Remarks on the Results yielded by the Chemical Examination of the Water in reference to the Observed Character of the Gathering Ground.*

It is of interest to note that while Ringstone Reservoir water was very acid on October 3rd, 1894, the "inlet" water from Mossmoor Catchwater was neutral on that date. A possible explanation of this difference in the quality of the two waters might be found by supposing that the peat, which undoubtedly is washed in large quantities into the reservoir, fermented in the bed of the reservoir. The probable, and, indeed, the almost certain explanation, however, lies in the fact that prior to October 3rd, 1894, the rainfall was much below the average, and, in consequence, the only water gaining access to the catchwater was from mooriand springs, which are usually not only neutral but possess some acid neutralising ability. On November 7th, 1894, after heavy rains, Mossmoor Catchwater contained a highly acid water, no doubt due to the enormous increase in the surface water, which, when draining from peat, seems invariably to be associated with acidity. The acidity, it is true, was not so great as the acidity of the reservoir water on that date (November 7th, 1894); but there is every reason to believe that at particular seasons of the year, or at particular periods during a storm—perhaps at the beginning—the conditions would be reversed.

The above affords an excellent illustration of the importance, in the case of moorland water supplies, of allowing only the "fair weather" flow to enter the waterworks. Unfortunately the failure to provide adequate arrangements for excluding storm water is only too common among waterworks, and in many cases, whether this provision exists or not, the exigencies of a constant and abundant supply necessitates the collection of all or nearly all the water draining from the catchment area, independently of its quality.

In conclusion, it is to be noted that the acid quality of the water obtained from this gathering ground, as judged by the state of the water contained in Ringstone Storage Reservoir, is quite in keeping with the observed character of the gathering ground. It has been shown that from the nature of the ground an enormous quantity of surface water derived from the drainage of peaty soil must enter the waterworks in storm time, and that it is only in time of drought, when the surface water is dried up, and the spring water alone enters the waterworks, that the quality of the water can be expected to be otherwise than peaty. Numerous experiments, which are detailed elsewhere, shows conclusively that water filtered (under laboratory conditions) through peat, and water draining (under natural conditions on moorland gathering grounds) from peat, acquires acidity and plumbo-solvent ability.

## WAKEFIELD CORPORATION WATERWORKS.

### TABLE 23.—*Chemical Results.*

| Experiment. | Description of the Sample of Water. | Hardness (CaCO$_3$ parts per 100,000). | Reaction with Lacmoid. | Acidity in Terms of c.c. $\frac{n}{10}$ Na$_2$CO$_3$ required to neutralise 100 c.c. of the Water. | Action on Lead (Result stated as Parts per 100,000). The action on lead was tested by upward filtration through 50 c.c. washed Lead Shot at the rate of 3 mins. per 50 c.c. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st 50 c.c. | 2nd 50 c.c. | 3rd 50 c.c. | 4th 50 c.c. | 5th 50 c.c. | Average |
| 1 | September 13th, 1894. Wakefield water ("treated" with Na$_2$CO$_3$) from tinned lined pipe in Dr. Whitelegge's house. | 2·4 | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 2 | September 14th, 1894. Wakefield water before "treatment" at "inlet" to Ardsley Reservoir. | 3·78 | Acid | 0·84 | 0·8 | 2·0 | 2·4 | 2·4 | 2·4 | 2·00 |
| 3 | October 4th, 1894. Ringstone Reservoir water—the sample of water was collected near point of entrance into reservoir of Lowmoor Catchwater. Wakefield Corporation Waterworks. | 3·9 | Acid | 0·66 | 1·2 | 2·0 | 2·4 | 2·4 | 2·4 | 2·08 |
| | November 7th, 1894. Ringstone Reservoir water—the sample of water was collected near the "outlet." Wakefield Corporation Waterworks. | 5·3 | Acid | 0·96 | 1·2 | 2·0 | 3·0 | 4·0 | 3·5 | 2·74 |
| 5 | November 7th, 1894. Mossmoor Catchwater at inlet to Ringstone Reservoir—the sample of water was collected after heavy rains. Wakefield Corporation Waterworks. | 4·6 | Acid | 0·60 | 0·4 | 1·2 | 1·6 | 1·4 | 1·4 | 1·20 |
| 6 | November 15th, 1894. "Inlet" water (from Ringstone Reservoir) to Ardsley Reservoir before "treatment" with Na$_2$CO$_3$. Wakefield Corporation Waterworks. | 5·4 | Acid | 0·90 | 2·0 | 2·5 | 3·0 | 3·0 | 3·0 | 2·70 |
| 7 | November 15th, 1894. Wakefield water (treated with Na$_2$CO$_3$) from iron pipe in Alderman Flower's house. | 3·1 | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| | September 6th, 1895. "Inlet" water (from Ringstone Reservoir) to Ardsley Reservoir before "treatment" with Na$_2$CO$_3$. Wakefield Corporation Waterworks. | 5·3 | Acid | 0·78 | 1·0 | 1·2 | 1·4 | 1·8 | 2·0 | 1·48 |
| 9 | September 6th, 1895. "Outlet" water from Ardsley Reservoir, after "treatment" with Na$_2$CO$_3$. Wakefield Corporation waterworks. | 3·2 | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |
| 10 | March 28th, 1896. "Inlet" water (from Ringstone Reservoir) to Ardsley Reservoir before "treatment" with Na$_2$CO$_3$. Wakefield Corporation Waterworks. | — | Acid | 0·84 | 1·5 | 2·5 | 2·5 | 3·3 | 3·0 | 2·56 |
| 11 | March 28th, 1896. "Outlet" water from Ardsley Reservoir after "treatment" with Na$_2$CO$_3$. Wakefield Corporation Waterworks. | — | Neutral | Neutral | 0·0 | 0·0 | 0·0 | 0·0 | 0·0 | 0·00 |

## SECTION III.—CONSIDERATION OF RESULTS OBTAINED FROM THE SEVERAL SURVEYS REPORTED IN SECTION II.

### ON PARTICULAR NATURAL CONDITIONS OF GATHERING GROUNDS IN RELATION TO THE PRESENCE OF PEAT AND TO THE PLUMBO-SOLVENT ABILITY OF WATER DERIVED FROM THEM. (*See* special notes of detailed Surveys, heading "*a.*")

High gathering grounds: moorland and upland gathering grounds compared.

Although all the waterworks surveyed derive their water supply from "high gathering grounds," yet some of them receive water from "upland areas" which are not essentially moorland in character.

Gathering grounds essentially moorland in character.

The following may be taken as being essentially moorland gathering grounds:—

Ashton-under-Lyne, Stalybridge, and Dukinfield Waterworks. Both the Swineshaw and Greenfield systems derive their water from moorland sources, but the former has more peaty water and less spring water than the latter.

Bacup Corporation Waterworks.

Bolton Corporation Waterworks. Entwistle and Springs (misnomer) systems.

Bradford Corporation Waterworks. Thornton Moor and Upper Barden drainage areas.

Burnley Corporation Waterworks. Cant Clough and Swinden gathering grounds.

Colne Waterworks. A portion of the higher Laneshaw drainage area.

Dewsbury and Heckmondwike Water Board. Nearly all the Dunford bridge gathering ground.

Halifax Corporation Waterworks. The greater portion of the gathering ground in the Hebble, Luddenden, Widdop, and Greave valleys.

Huddersfield Corporation Waterworks. Blackmoorfoot drainage area.

Keighley Corporation Waterworks. Practically the whole of the Watersheddels gathering ground.

Morley Corporation Waterworks.

Nelson Corporation Waterworks. To some extent the Coldwell and Ogden systems derive their water supply from moorland sources.

Oldham Corporation Waterworks.

Rochdale Corporation Waterworks.

Sheffield Corporation Waterworks. High level supply.

Shipley Waterworks.

Wakefield Corporation Waterworks.

Preston and Blackburn Corporation Waterworks are on the whole to be regarded as moorland gathering grounds.

Typical moorland gathering grounds.

Of these the following appear to stand out pre-eminently as typical moorland gathering grounds, namely:—

Bacup Corporation Waterworks gathering ground.

Bradford Corporation Waterworks. Thornton Moor gathering ground.

Halifax Corporation Waterworks. Fly gathering ground.

Huddersfield Corporation Waterworks. Blackmoorfoot gathering ground.

Keighley Corporation Waterworks. Watersheddels gathering ground.

Morley Corporation Waterworks gathering ground.

Shipley Waterworks gathering ground.

Wakefield Corporation Waterworks gathering ground.

**Gathering grounds not pre-eminently moorland in character.**

Barnsley Corporation Waterworks is an example of a waterworks which derives its supply from "upland sources" which are only partly moorland in character. Thus, the total area of the watershed is 1,910 acres; of this about 227 acres are arable land, 445 acres meadow land, 622 acres pasture land, 373 acres *moorland*, and 243 acres road, streams, reservoirs, quarries, and waste places.

Batley Corporation Waterworks gathering ground is to be regarded as an upland gathering ground only partially moorland in character, and having a large portion of the total area covered with pasture grass growing on soil which is not very peaty.

Again, the High Rid supply (Bolton Waterworks), Springs supply (Burnley Waterworks), Floss, Barnside, and Bonnie Booth supplies (Colne Waterworks), can hardly be regarded as derived from moorland sources.

Also the Leeds Corporation Waterworks and the low-level supply of Sheffield Corporation Waterworks obtain their water from upland, but not, perhaps, essentially moorland gathering grounds.

**Difference one of degree rather than of kind.**

In general terms, in the sense of this report, a moorland gathering ground is one rich (superficially and in depth) in peat, with heather and moss but little pasture grass. Situated usually at a considerable elevation above sea level, it comprises portions which are commonly flat, and areas where the rain stagnates in peaty, marshy, and boggy places. It yields a large amount of surface water and but little spring water. On the other hand, an upland gathering ground, in the sense of this report, is one which is covered with soil not peaty, or only partially peaty, in character, and which supports the active growth of grass but has little or no heather. In general it is situated at a somewhat lower level than "moorland" areas, and does not allow of much stagnation of water in the surface soil. It yields a fair amount of spring water as well as surface water. Of course the one passes into the other. Every moorland gathering ground is necessarily also in part an upland one, but still no part of an upland gathering ground need be "moorland" in the above sense.

**Moist peat invariably acid.**

**Experiments bearing on the result of contact of water with peat as regard acidity.**

In 1893 it was found, as the result of testing in many places, on different gathering grounds and at all seasons of the year, that moist peat soil is invariably acid. This observation of the acid quality of the peat itself led to an elaborate series of experiments the results of which clearly point to the fact that moorland waters when they have left the peat have completed their life history so far as acidity is concerned, and that their acid condition is due to their having carried out of the peat an acid or acids manufactured *in sitû* as a result, as is believed, of the vital processes of bacteria.

But whether the acid manufactured in the peat is to be regarded as the result of a biological process or a chemical change, or both combined, matters very little from the practical point of view, and so far as the actual result is concerned. This result has been already indicated, and was abundantly illustrated during the surveys. Water that has been brought into contact with peat carries with it an acid or acids capable of dissolving lead to an extent chiefly governed by the amount of the acidity.

The observations made, as a result of the inspection of the different gathering grounds, as regards the amount of peat and its distribution, are thus of the greatest importance. To realise this fully reference must be made to each separate survey.

**Distribution of peat.**

It would have been of considerable interest to have shown in connexion with each survey map the "peat areas" marked in some distinguishing way, illustrating not only the superficial extent of the peat but its depth. For reasons that are sufficiently obvious, the information necessary to effect this object was either not obtainable or was not altogether reliable. Nevertheless, in one or two maps an attempt has been made to show the distribution of the peat.

**Gathering grounds specially peaty.**

Of gathering grounds especially peaty the following are worthy of note:—

Bacup gathering ground (Bacup Corporation Waterworks).
Fly gathering ground (Halifax Corporation Waterworks).
Blackmoorfoot gathering ground (Huddersfield Corporation Waterworks).
Watersheddels gathering ground (Keighley Corporation Waterworks).
Mytholmroyd gathering ground (Morley Corporation Waterworks).
Ringstone gathering ground (Wakefield Corporation Waterworks).
Shipley gathering ground (Shipley Waterworks).

**Gathering grounds less rich in peat.**

Of gathering grounds which are not very rich in peat the following may be named:—

Barnsley gathering ground (Barnsley Corporation Waterworks).
Barrow-in-Furness gathering ground (Barrow-in-Furness Corporation Waterworks).
Batley gathering ground (Batley Corporation Waterworks).
Leeds gathering ground (Leeeds Corporation Waterworks).
Sheffield low-level gathering ground (Sheffield Corporation Waterworks).

Most of the other gathering grounds occupy an intermediate position as regards peat.

As an example of a gathering ground peculiarly rich in peat, the Fly system of water supply of the Halifax Corporation Waterworks may be mentioned. Here the drainage area covers 919 acres, and is situated at an elevation of 1,350 feet above sea level. In many places the peat beds are over 10 feet in thickness, and the whole of the drainage area is covered with a layer at least 2 feet in thickness. Fortunately the water draining from this gathering area is used chiefly for compensation purposes.

**Peaty water.**

Running parallel with the question of the amount of peat on the gathering ground is the question of the amount of peaty water gaining access to the supply. The greater the amount of peat on a gathering ground, the greater is likely to be the amount of peaty water relative to the total yield of water. But in some cases the amount of water draining from surfaces more or less peaty may be large in bulk, and yet the water may be only slightly peaty in character, and in other cases the peaty water may be small in amount, but owing to prolonged contact with the peat be, as it were, a concentrated water so far as the peaty element is concerned. So that in judging of the evil effect likely to be produced by a particular water entering a waterworks, note must be taken, not only of the amount of peat or the products of the decay of peat in such water, but also of its bulk relative to other non-peaty water reaching the supply. As to the amount of peat or its products in a given sample, this may be judged of partly by observation of its colour, by the appearance of the suspended matter contained in it, and by chemical analysis, but, from the point of view of this inquiry, is chiefly to be determined by the amount of acid contained in it.

As as example of a waterworks storing a water highly acid, very peaty, and of large amount, Shipley may be cited. Here there are three large streams which constitute the main sources of supply. These streams are comparable in that they all drain exceptionally peaty land. Also they come under the same category as regards acidity, all of them being very acid waters.

Here then we have a water draining from land which is exceptionally peaty, which is very acid, and which is of large bulk.

In other cases we may have a water draining from very peaty land and rich in acid, but of relatively small bulk. For example, the water carried from the moor through iron pipes into the S.W. side of Thornton Moor reservoir (Bradford Corporation Waterworks). Also Fletcher's Dyke, Great Rut, and Deep Slade streams, which discharge into Withen's Reservoir (Morley Waterworks). These waters drain land exceptionally peaty, and are highly acid, but they are of relatively small bulk under ordinary conditions of rainfall.

As an example of a water draining land only partially peaty in character, and only slightly acid, but of large amount, mention may be made of the water supplying Widdop reservoir (Halifax Corporation Waterworks), which comes from the Widdop and Greave Valleys, where there is only a sparse distribution of peat.

**Spring water.**

Of nearly equal importance with the notes on the extent and distribution of peat and the amount of peaty water, are the notes which deal with the amount of spring water gaining access to the waterworks. Speaking from a very large number of experiments, it may be stated that moorland spring waters are not only neutral and free from plumbo-solvent ability, but that they possess acid-neutralising ability,* and consequently ability to annul or lessen plumbo-solvency. It is true that this neutralising force is not usually present in marked degree, yet it is sufficient in not a few cases to place an otherwise dangerous water in a condition of practical safety, so far as risk from lead-poisoning is concerned. Examples have already been given of waterworks where the proportion of spring water to surface water is very small, and others where the conditions are more satisfactory in this respect. It was pointed out that while the acid neutralising ability of moorland spring water is not great, and is fairly uniform, the acidity of peaty water varies within relatively wide limits. Again, it was noted that the ultimate state of a *mixed* moorland water depends very largely on the relative proportion of spring and peaty waters, and the *degree* of acid neutralising ability of the former and the amount of acidity of the latter. Sometimes the good effect of a fairly abundant supply of spring water is lost in the excessive acidity of a comparatively small bulk of peaty water. Again, sometimes the spring water is relatively small in amount and the peaty water abundant, but the latter may be so slightly peaty in character as not to overcome the acid-neutralising ability of the spring water. As a matter of practical observation, it may be said that when a moorland water as sent into consumption is acid, the gathering ground is rich in peat, storm water is allowed to enter the waterworks, and the dry weather flow is deficient in amount—the last, of course, being largely derived from springs. Conversely, when a moorland water as sent into consumption is neutral, then the gathering ground is usually only partially peaty in character; there is frequently also provision made for excluding storm water from the waterworks, and the amount of spring water is commonly sufficient to ensure a good fair weather flow. The reason why spring water is so deficient on moorland gathering grounds is no doubt to be traced to the high elevation of these drainage areas. Much of the water sinking in the ground must crop out at a lower level than the lowest point of "intake" for waterworks purposes. There can be no question that such water, after passing through the deeper strata of rock would be extremely valuable for waterworks purposes, and would be likely to neutralise a much larger body of water than the small amount of spring water which reaches the surface at a sufficiently high elevation to allow of its being utilised. This is a circumstance which has perhaps not been taken sufficient notice of by waterworks officials in the past, but which is likely to assume greater prominence in the future.

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* It is to be noted that spring waters are referred to as possessing alkaline properties or acid-neutralising ability, not as "alkaline waters"; the reason being that it is doubtful if any potable water is alkaline in the same sense as peaty waters are unquestionably acid.

**Factors of acidity other than peat: acid rain water and presence of iron pyrites.**

**Acid rain water.**

Other factors may be at work in producing acidity, and must here be considered, namely, the oxidation of iron pyrites, and the presence of sulphurous or other acid in the rain falling on the gathering ground. This last factor, even if it be supposed to be a uniform source of acid, is quite inadequate to explain the extreme acidity observed in so many moorland waters, and throws no light on those cases where the rain, after collecting and lying stagnant in hollows or depressions in the peat, is found to be very strongly acid. Rain water collected in glass vessels on these gathering grounds, although frequently showing a certain degree of acidity, never showed an amount of acidity at all corresponding to the amount of acid found in peaty waters. Rain water collected at a height of about 600 feet above sea level in a country district, in places remote from the possibility of contamination with smoke from manufactories, showed no acidity. In a future report tables will be given dealing with this matter more fully. But it may here be definitely stated that the feeble acidity observed in certain cases in the rain falling on the gathering grounds is quite inadequate to explain the acidity of moorland waters.

**Iron pyrites.**

**Ochre springs.**

As regards the presence of iron pyrites, there can be no doubt that pyrites in the presence of water and moisture would undergo oxidation changes leading to the formation of sulphuric acid.* But as a matter of fact, so far as could be ascertained on the particular gathering grounds examined, the strata bearing pyrites usually crop out at a much lower level than the level of the lowest intake for waterworks purposes; and the water issuing from the rock on the gathering grounds as spring water† was invariably found to be neutral, and even possessed of acid neutralising ability. Such of these springs as contained iron in large amount (ochre springs) contained it apparently in the form of carbonate, held in solution by carbonic acid, and the iron was deposited very rapidly on exposure to the air, forming bright orange coloured deposits along the course of the streams. These waters, too, were found to be neutral and free also from plumbo-solvent ability.

**Deposit of iron in peat and marl.**

The iron in the substance of the peat and in the marl underlying the peat appeared to be present in the form of oxide or carbonate. Deposits of iron are commonly found both in the peat and in the marl, but experiments with these deposits with a view to discovering whether or not they were concerned in the production of acid always gave a negative result, and it may be concluded that the presence of iron, in this form at all events, has seemingly no relation to the acidity of peaty waters.

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* The following equation may be taken as representing the action :—$Fe\ S_2 + H_2O + 7\ O = Fe\ SO_4 + H_2\ SO_4$.

† Moreover, there is every reason to believe that the water issuing from the rock low down in moorland valleys is not only not acid, but possessed of a higher degree of acid neutralising ability than water reaching the surface at a higher elevation, although both waters perhaps trace their origin to rain falling on the same area.

Ferruginous shale and sandstone.

Water from certain more superficial layers of rock which is frequently rich in iron (for example, shale and sandstone), on which peat directly or indirectly rested, was tested in a variety of ways. These experiments tended to show that the rock conferred no acid properties on neutral water, and not only did not increase the acidity of acid peaty waters, but rather tended to neutralise the pre-existing acidity.

Example of an acid water draining from pyritic rock.

But on one gathering ground (Rochdale Corporation Waterworks) a water was found which was extremely acid. This water drained from a disused mine, and samples of this rock were found on examination to be very rich in iron pyrites. An artificial filter was constructed, made up of large and small portions of the rock, and neutral water was filtered continuously through it for a number of weeks. The filtrate was always exceedingly acid, and when sufficiently diluted with water dissolved lead to an enormous extent. Details of these results will be given in a future report.

It has been said that the amount of the acidity in the rain falling on moorland gathering grounds is quite insufficient to explain the acidity of moorland waters. The same cannot be said as regards the acidity produced by the oxidation of iron pyrites, and there can be no question that a water such as was discovered on the Rochdale Waterworks, gaining access to a supply, would contaminate it to an alarming extent. But so far as could be ascertained by personal inspection, and on inquiry, the Rochdale case is the exception and not the rule, and although in certain isolated cases the acidity may be traceable to the oxidation of iron pyrites in rock, it is quite certain, as the result of very numerous experiments under many different sets of conditions, that the acidity produced in water by contact with peat is an invariable and constant factor. It is only right to state that the Rochdale water above referred to no longer gains access to the waterworks.

Geological notes.

Other considerations, geological and physical, have to be thought of as influencing the composition of moorland water from the point of view of this inquiry. For example, the geological formation on the gathering ground, the nature of the rock (using the word in its broadest sense) immediately beneath the surface soil, the nature of the beds of the moorland streams, and the distance these streams run before entering the storage reservoirs. Also the nature of the vegetation, whether pasture grass, heather, or moss, the amount of denudation of the sides of the valleys, the slope of the hills (whether precipitous or not), the drainage from the soil (whether slow or rapid), and the presence of flat areas on the higher parts of the gathering grounds, allowing of rain stagnation in hollows or depressions.

Millstone grit, shale, flagstone and sandstone rock.

These physical conditions have been taken into consideration in all the different surveys, and is it desirable at this stage to sum up in a general way the bearing of these points on the quality of a moorland water.

On most of the gathering grounds the geological formation is millstone grit, *e.g.*, Leeds, Wakefield, Oldham, Huddersfield, Blackmoorfort supply, Dewsbury &c., gathering grounds. Shale and flagstone and sandstone rock are commonly met with.

Immediately beneath the peat is usually, but not invariably, a layer of marl. Experiments have been tried with powdered shale and sandstone rock to see whether these substances in the presence of water and oxygen can give rise to acidity. It was found not only that no acid was manufactured, but that when naturally acid waters were left in contact with these materials they suffered a slight diminution of acidity. On one gathering ground there was a leak in one of the reservoirs, and the water thus escaping, and after pouring through a considerable thickness of rock came to the surface at a lower point in the valley. This reservoir water was very appreciably acid, yet the water from the leakage, after passing through the rock, was neutral.

**Experiments with powdered shale and sandstone rock.**

**Effect of leak in a reservoir.**

It has been asserted that a moorland gathering ground ceases to yield an acid water after the feeders and streams have worn a channel for their flow through the peat on to the rock or marl. To show how groundless such assertions are the case of Shipley waterworks may be mentioned. Here the three main sources of supply are from Graincliffe, Weecher, and Blackdyke streams. These streams run for the greater part of their length on clay rock and sand bottoms. Yet they yield a continuous supply of highly acid water, and water also possessed of powerful action on lead.

In this particular case the gathering ground is very flat, and the bed of the stream is not subject to constant renewal by denuding agencies. Where denudation is extensive, as for example where a stream runs at the foot of a gorge with precipitous sides, the case is different. Here there is not only a constant washing of peat, but also of disintegrated rock and sand into and along the bed of the stream. That this may in certain cases have an important action in neutralising a part of the acidity is extremely probable. But it is to be noted that the same rock and the same sand cannot be supposed to possess a continuous power of neutralising acid. Dowry Beck (Denshaw system, Oldham Corporation Waterworks) is a good example of a moorland stream which receives enormous quantities of shale and sand washed with every storm from the surrounding hill slopes into its bed, and yet remains acid.

**Denudation of hill slopes.**

On many gathering grounds the hills which flank the streams are precipitous. On these hill slopes the peat beds are frequently not only very thin, but in many places absent, and there may be large portions where there is no surface peaty soil, but bare areas of rock, it may be, in the form of beds of disintegrated shale or sand, circumstances which may be regarded as favourable to the quality of the water. Some such state of things holds good as regards Ogden and Skirden Cloughs (Halifax Corporation Waterworks).

**Sparse distribution of peat on steep hill slopes.**

Moreover, precipitous slopes necessarily favour rapid drainage from the soil, which inhibits acid formation in the peat, and frequently allows an abundance of spring water, which has an acid-neutralising ability, to crop out and reach the supply.

For example, a large body of spring water issues from the precipitous hill sides on the west side of Yeoman Hey reservoir (Ashton-under-Lynes Stalybridge and Dukinfield Waterworks), and if we exclude the water draining from the tops of these hills where the land is flatter the rain water falling on the slopes of the hills passes rapidly into the storage reservoir.

**"Cropping out" of spring water.**

Another example is the River Don (Dewsbury and Heckmondwike Waterworks) along the lower part of its course. Here the water from the upper reaches (Grain, Little Grain, and Swinehill Cloughs) is acid even during dry weather flow—the rain tending to stagnate on the upper and flatter portions of the gathering ground, and bring therefrom a large

**Upper and lower "reaches" of a moorland river compared.**

body of peaty water, and but little spring water. Lower down the conditions are very different as the hill slopes bordering the river are precipitous, there is a sparse distribution of peat, and a large amount of spring water as well as some peaty water gains entrance to the supply. The result of this more favourable condition of things was well seen on the date of inspection. The reaction of the water changed from above downwards from a water distinctly acid to one slightly acid, and then finally to a neutral water.

In all, or nearly all, the surveys allusion is made to the surface vegetation.

Heather on gathering grounds.

Most of the moorland gathering grounds are covered with heather, and coarse pasture grass is also frequently present. The gathering grounds yielding the most acid water are usually those where heather is abundant, the reason being that such areas are rich in peat. But on some gathering grounds, or portions of them, there may be a great deal of black peat and mossy and marshy ground with very little heather, and yet such areas usually yield a highly acid water. The gathering grounds yielding a neutral water or a water only slightly acid are commonly those where grass very largely takes the place of heather. It may generally be inferred that the active growth of grass implies a soil only partially peaty in character, and one well drained. This alone would account for the observed fact that water draining from an area supporting an active growth of grass is usually neutral or only very slightly acid, quite apart from any intrinsic effect produced by the growth of vegetation. It is no doubt the case that the grass may "bind" the soil and absorb much of its moisture, and render it less spongy and less able to retain water, and thus inhibit the formation of peat. However this may be, the fact remains, that water draining from *grassy* moorland is usually neutral or only very feebly acid; whereas water draining from moorland, where there is but little grass and the vegetation consists chiefly of heather and moss, is frequently acid.

Grassy vegetation.

Pasture grass compared with heather and moss.

To take one or two examples :—The Batley gathering ground supports the active growth of grass, and the water draining from it is either neutral or only very slightly acid. A large portion of the Barrow-in-Furness and Barnsley gathering grounds is grass covered, and these waterworks store a neutral water. On the Shipley and Bacup gathering grounds grass is almost absent, and the vegetation is chiefly heather, moss, and rank grass. Here the water is of bad quality as regards acidity and plumbo-solvent ability.

Incidentally, reference has been made to the beneficial effect of rapid *drainage* from the soil in the case of moorland waters.

Effect of rapid surface drainage.

Given a certain amount of peat on a gathering ground, the amount of acid which it is likely to yield depends very largely on the length of time the water remains in contact with it. If the drainage is satisfactory the rain may run off the surface, and at all events does not remain in contact with the peat for a long period; whereas, if the drainage is bad then the rain may saturate the peat, and if the peat rests on an impervious stratum may only escape by lateral percolation through a great thickness of peat. Moreover, under the latter set of conditions, each successive rainfall displaces water which has been lying stagnating in the soil, it may have been for a considerable time. Take, for example, the Shipley gathering ground. Here peat is abundant superficially and in depth, and rests on clay. Moreover, the slope of the ground is very gradual. In consequence, the rain saturates the peat and accumulates in hollows or depressions forming peat holes and boggy and marshy places. It escapes very slowly into the feeders leading to the reservoirs

Examples of slow surface drainage from peaty soil.

by lateral percolation through immense thicknesses of peat. As a result the water is habitually strongly acid. Nearly all the gathering grounds suffer to a great or less degree from slow drainage from the surface soil on a portion of their gathering ground. Commonly some such state of things prevails on the upper and flatter portions of the gathering grounds.

Many instances might be quoted in illustration, but the following may be deemed sufficient:—

Fly system (Halifax Corporation Waterworks); large areas on the gathering grounds of the Bacup Corporation Waterworks; portions of the Oldham Corporation Waterworks (*e.g.*, upper part of the Denshaw system of supply); Bradford Corporation Waterworks (S.W. side of Thornton Moor reservoir); Keighley Corporation Waterworks (portions of Watersheddels drainage area); large areas on the gathering grounds of the Morley Corporation Waterworks; Sheffield Corporation Waterworks (high-level supply).

**Effects of slow surface drainage.**

In all these cases the effect of the stagnation of the water in the peat is to foul the general body of water supplying the impounding reservoirs with water distinctly acid and possessed of considerable plumbo solvent ability.

**Beneficial effect of rapid surface drainage.**

On the other hand, many instances might be quoted to show that the evil effect of the presence of extensive beds of peat may be reduced to a minimum, where the slopes of the hills are sufficiently steep to permit the water to drain rapidly away. This favourable circumstance, namely, rapid drainage from more or less peaty soil is found in the case of many gathering grounds. Some such state of things holds good in the case of the following waterworks among others, and as regards a large portion of their gathering grounds:—

Batley Corporation Waterworks; Barnsley Corporation Waterworks; Barrow-in-Furness Corporation Waterworks; Blackburn Corporation Waterworks; Preston Corporation Waterworks, &c.

There has thus to be considered in connexion with moorland gathering grounds, not only the presence of peaty soil but the nature of the drainage from such soil—whether slow or rapid. For of two gathering grounds covered with a similar amount of peat (superficially and in depth), the one, from porosity of the rock underlying the peat or from the steepness of the hill slopes, or from both these causes combined, might yield a neutral or only faintly acid water; whereas the other, from the presence of clay beds beneath the peat, or the flatness of the ground, or from both these causes combined, might facilitate stagnation of the rain in the peat, and so yield a highly acid water.

### Certain Differential Conditions of the several Waterworks and Gathering Areas surveyed in their relation to Plumbo-solvency. (*See* detailed Surveys, heading "Sources of the Water Supply and general description.")

**Situation of gathering grounds in relation to the area supplied with water.**

As might be expected, the gathering grounds of the different waterworks are frequently situated at a considerable distance from the towns supplied with water by them.

This circumstance is one of importance, because the "mere delay" of a water in the impounding reservoirs and its subsequent passage through, in many cases, miles of iron pipe to the service reservoir, may conceivably produce some alteration in the composition of the water.

The gathering grounds of Barnsley, Barrow-in-Furness, and Bradford (high level) Waterworks are situated about 10 miles from the towns of the same name. Batley, Blackburn, Morley, Bradford (low level), and Preston Waterworks are situated about 20 miles from their chief areas of supply. The most distant part of the gathering ground supplying Leeds with water is situated 22 miles away. Wakefield obtains its supply from gathering grounds distant 26 miles.

In a later report it will be shown what the effect of "storing" moorland water is as regards acidity, so far, indeed, as this can be judged of by placing such waters under laboratory conditions of experiment. Here it may be said that the general outcome of these experiments was as follows:—When an acid peaty water was stored for varying periods in completely filled and stoppered bottles, the acidity was usually only very slightly reduced in amount, but practically never suffered an increase. When such water was kept in unstoppered and partially filled bottles there was usually a distinct loss of acidity. These results indicate what might be expected in the case of a water which has a comparatively long stay in conduits or pipes.

Capacity, &c. of reservoirs.

Under the heading "*Capacity, &c. of Reservoirs,*" notes have been usually given of the capacity, depth, area, and top water level of the storage reservoirs. The greater the capacity of the reservoirs the more complete is the sedimentation of the water likely to be and the less likely is the water sent into consumption to show the results of the entrance of storm water. Moreover, the greater the capacity of the storage reservoirs, as just indicated, the longer the delay will be between the primary collection of the water and its final transmission to the consumers. But it must be remembered that the bed of some of these reservoirs is composed of peat, and that fresh peaty matters are washed into the reservoirs with every storm. In consequence, although there may be a loss of acidity due to long exposure of the water to the action of the air, there may also be a gain in acidity due to fermentative changes in the bed of the reservoirs.

Height of storage reservoir.

These storage reservoirs, as might be expected, are situated at a considerable height above sea level.

Thus the top water level (in feet) of Blackmoorfoot reservoir (Huddersfield Corporation Waterworks) is 831; of Graincliffe reservoir (Shipley Waterworks) is 845; of Lanshaw reservoir (Colne Waterworks) is 858; of Cant Clough reservoir (Burnley Waterworks) is 924; of Coldwell reservoir (Nelson Waterworks) is 943; of Withen's Clough reservoir (Morley Waterworks) is 960; of Ringstone reservoir (Wakefield Waterworks) is 994; of Watersheddel reservoir (Keighley Waterworks) is 1,100; of Dunford Bridge reservoir (Dewsbury Waterworks) is 1,100; of Readycon Dean reservoir (Oldham Waterworks) is 1,268; and of Fly reservoir (Halifax Waterworks) is 1,350.

Depth of reservoirs.

In depth the storage reservoirs vary from less than 30 feet (Sheephouse reservoir, Bacup Waterworks) to 100 feet (Entwistle reservoir, Bolton Waterworks).

Area of reservoirs.

The area covered by the reservoir may be less than 10 acres (Eldwick reservoir, Shipley Waterworks) or more than 150 (Fewston and Swinsty reservoir, Leeds Waterworks).

Capacity of reservoirs.

As regards capacity, this may be less than 50 million gallons (Hechenhurst reservoir, Burnley Waterworks; and (Eldwich reservoir, Shipley Waterworks) or more than 900 million gallons (Swinsty reservoir, Leeds Waterworks).

It has been already noted that there are no storage reservoirs on the gathering grounds of the Blackburn and Preston Corporation Waterworks.

When the enormous capacity of some of these reservoirs is considered in relation to the fact of observed acidity in the water contained in them, the importance of observations on this point is evident. A large reservoir might permit the storage for subsequent consumption of hundreds of millions of gallons of acid water, and water, moreover, capable of disolving lead to a dangerous extent.

**Different modes of collecting and storing the water, and of sending it into consumption.**

It will have been noted that the arrangements for collecting and storing the water in the different waterworks vary a good deal. Not uncommonly an embankment is erected across a narrow valley so as to form a reservoir above it, into which all the streams draining the hills on either side flow, but which derives its main source of supply from one or more streams entering the upper end of the reservoir. Also there are frequently catchwater conduits which may follow the contours of the neighbouring hills for several miles, collecting all the water draining from these hills, and eventually discharging their contents into the reservoir.

In the case of Morley Corporation Waterworks, there is only one reservoir, and it is supplied with water as follows: On the north side three streams and the water from a catchwater conduit draining a large area of moorland. On the south side three streams and the water from another catchwater conduit draining a considerable tract of moorland. At the upper end of the reservoir the water from the main inlet stream enters.

Sometimes a catchwater conduit is responsible for the main bulk of supply water to a reservoir.

In the case of Wakefield Corporation Waterworks there is only one reservoir on the gathering ground, and practically its only source of supply is from Mossmoor catchwater, which is nearly 5 miles in length, and collects at its upper end the water from a moorland stream—Spa Clough. Along its course this catchwater receives the drainage from a very large tract of moorland.

Occasionally there are no storage reservoirs on the gathering grounds, the only reservoirs being the service ones.

In the case of Blackburn Corporation Waterworks the water from the Brennand and Whitendale Valleys is received in each instance into a screen chamber. The water, after passing in each instance through a screening chamber, is carried by a 30-inch cast-iron pipe from the chamber to Footholme. Here the Brennand and Whitendale waters unite, and are carried in a single 30-inch main (Bowland main) to three *service* reservoirs. Preston Corporation Waterworks derives its supply from the Rivers Langden and Hareden, in the valleys of the same name. The water, after passing through a screen chamber in each instance, unites and passes along a covered conduit to the *service* reservoirs. Nelson Corporation Waterworks derives part of its supply from the Ogden Valley. Here there is no reservoir (except for compensation purposes), the water being taken directly from a moorland stream known as Ogden Water, and led on to filters; thence after filtration the water is carried by an iron main over Pasture Head to Nelson.

Sometimes, in connexion with waterworks, an arrangement exists whereby water collected on a gathering ground may be sent directly into supply during fair weather flow, and indirectly, through storage reservoirs, during storm time.

In the Greenfield supply of Ashton-under-Lyne, Stalybridge, and Dukinfield (district) Waterworks a number of valuable springs exist on the west side of Yeoman Hey reservoir. During floods their water flows into the reservoir, but under ordinary conditions of the rainfall the springs are allowed to discharge into a common channel leading to settling and straining tanks, from whence the water can be sent directly into consumption.

**The number of storage reservoirs varies in different cases.**

In some of the waterworks there is a large number of reservoirs on the gathering ground, a circumstance which may materially affect the quality, as regards lead dissolving properties, of the water delivered to the consumer. For example, Oldham Corporation has no less than four reservoirs on the Denshaw gathering ground; other five reservoirs, and a sixth in course of construction (two are used only for compensation purposes), on the Piethorn gathering ground; and, further, two reservoirs on the Castleshaw gathering ground. Much of the water at Oldham, therefore, has to pass through a number of reservoirs before being carried into consumption.

The following is an instance of a water the character of which is materially altered by passing through a series of reservoirs. Readycon Dean reservoir is supplied from a moorland stream. The water from Readycon Dean passes into Crook Gate reservoir. Dowry reservoir receives the water from Crook Gate and Dowry Beck, and discharges into New Year's Bridge. From this latter reservoir the water is conveyed by a tunnel and line of pipes to Hanging Lees reservoir. A main carries part of the water from this reservoir to the higher parts of Oldham, but most of the water is allowed to pass into Piethorn reservoir, and from thence is conveyed by another main to Oldham.

Not uncommonly waterworks derive their supply from several different valleys. The water in these cases may be either mixed before being sent into consumption, or sent in an unmixed condition to different portions of the area supplied.

**The water may be collected from one or from several valleys.**

For example: Halifax Corporation Waterworks derives its supply from Hebble, Luddenden, Widdop, and Greave Valleys. There are three systems of supply, namely, the Ogden system (Hebble Valley), the Fly and Dean Head system (Luddenden Valley), and the Widdop and Greave system (Widdop and Greave Valleys) Briefly stated, the arrangements for collecting water are as follows:—Ogden reservoir is supplied with water from Ogden and Skirdew Cloughs, and by means of a conduit the reservoir water is conveyed to Ramsden Wood reservoir. Fly reservoir is supplied chiefly from a catch water drain 1¾ miles long. The water is used chiefly for compensation purposes. Lower Dean Head reservoir is supplied from Upper Dean Head, which is fed chiefly from two moorland streams. Lower Dean Head reservoir water unites with the water from the Widdop and Greave system, and the combined water discharges into Ramsden Wood reservoir. Widdop reservoir is constructed on the Widdop stream, and also receives, by means of a tunnel, the water of the Greave Valley, so that there is one reservoir for the combined drainage of two valleys. The water from this reservoir is conducted by pipes and tunnel to Shore End Wood, where it joins the Fly and Dean Head water and passes with it into Ramsden Wood reservoir. Thus Ramsden Wood reservoir contains the mixed water from the Ogden, the Fly and Dean Head, and the Widdop and Greave systems. The water from Ramsden Wood is carried to the Albert and Victoria service reservoirs for distribution in the borough. Widdop, Fly, Upper and Lower Dean Head, and Ogden reservoirs are storage reservoirs situated on the gathering grounds. Ramsden Wood, Albert and Victoria reservoirs are service reservoirs, the first named being used for mixing and then screening the water, and the two latter for distributing it in the town.

Admixture of water from various systems and of different origins may be of great importance as regards plumbo-solvency. It may, for example, be beneficial, as where the water from one system is acid, while the water from the other systems is not only neutral, but possessed of acid neutralising ability. In such a case the mixture of all the waters together may produce a water free from even traces of acid. On the other hand, as has been indicated, it may be harmful, as where a neutral water is supplemented by a large volume of peaty water, capable of acting upon lead.

In the case of Bradford Corporation Waterworks there is a high level and a low level service. The high level supply is obtained from the Thornton Moor and Stubden Valleys, and the low level supply from the Upper and Lower Barden Valleys. The former is used for the higher and the latter for the lower levels of the town. In the case of Rochdale Corporation Waterworks there are three systems of supply, namely, Hamer Pasture, Spring Mill, and Corvin. The mains from these separate systems are connected together, so that the water supply can be afforded either separately or in conjunction, as circumstances require.

**Mixing waters of different qualities as regards lead.**

The following is an instance where a waterworks supplements its own supply, free, so far as can be ascertained, from serious risk as regards lead, with water from another drainage area belonging to different waterworks which is liable to yield water with a decided plumbo-solvent action.

By agreement with the Dewsbury and Heckmondwike Waterworks Board, the Corporation of Barnsley purchase from the board a minimum quantity of 20,000,000 gallons, or a maximum quantity of 40,000,000 gallons per annum, which they may commence to take on July 1st in each year, and continue to take at the rate of 200,000 gallons per day for a minimum of 100 days or a maximum of 200 days consecutively. The maximum quantity has been taken only once, viz. in 1893. The water thus purchased from the Dewsbury and Heckmondwike Waterworks comes from Durnford reservoirs, and discharges into Broadstone Dyke, a moorland stream which enters the upper end of Ingbirchworth reservoir. This water was acid on July 11th, 1895, whereas all the other waters tested on the Barnsley gathering ground on the above date were neutral.

In connexion with Batley Corporation Waterworks there is an arrangement by means of which the streams *below* the level of the storage reservoirs are intercepted in dry weather and taken direct to Batley. All the main streams and subsidiary feeders and springs in the Ramsden valley below the level of Yateholme reservoir are collected at one point by iron conduits regulated by penstocks and sluice valves in order to intercept the dry weather flow which would not gravitate into Yateholme reservoir. This water is then taken direct to Batley, instead of being allowed to run into the compensation reservoirs. Such an arrangement has the advantage that the reservoir water can under ordinary conditions be kept at a high level without any flood water being admitted into it.

**Size of drainage areas.**

*Drainage areas.*—A note has usually been given of the size of the drainage area of the different waterworks, and where a waterworks has more than one drainage area, the size of each separate area has commonly been stated.

From consideration of these data it appears that in not a few cases the drainage areas, although sufficiently large to yield an adequate supply of water of all sorts (*i.e.*, independently of its quality), may yet be too small to allow of careful selection of water according to quality. In several instances the drainage areas can yield sufficient water to the waterworks only when "storm" water as well as "dry weather flow" is utilised. As regards lead, however, sufficiency of the total collecting area is less in question than the physical characters of the area. Of two drainage areas similar in size, and with the same rainfall, the one may be ample and the other insufficient in as far as supply of water of proper quality as far as lead is concerned, because the one may yield little or no *peaty* water and the other may yield water derived almost solely from the drainage of land rich in peat.

Sheffield and Leeds Corporation Waterworks have large drainage areas, namely, Sheffield, 15,703 acres (total drainage area of existing works); Leeds, 17,047 (Fenston and Swinsty drainage areas). The smaller waterworks have naturally much smaller drainage area, for example, Bacup, 285; Shipley, 1,248; Morley, 1,200; Colne (Laneshaw drainage area), 779 acres.

**Average yearly rainfall.**

It will be noted that often there is a considerable difference between the average yearly rainfall on the gathering grounds and the areas supplied with water, and that in nearly all cases the rainfall is heavy on the catchment areas. It is, indeed, this circumstance of heavy rainfall on upland gathering grounds which allows of a sufficient body of water being collected for waterworks purposes from sometimes a comparatively small drainage area. To take a few examples :—

AVERAGE YEARLY RAINFALL IN INCHES.

| Waterworks. | Area Supplied. | Gathering Ground. |
|---|---|---|
| Barnsley - - - - - | 25·12 | 38·15 |
| Barrow - - - - - | 38 | 52·57 |
| Battery - - - - - | 23·87 | 58·43 |
| Blackburn - - - - - | 38 | 59 |
| Oldham - - - - - | 36 | 42 |

Often the greater the distance between the area supplied and the gathering ground, the greater also is the difference in the rainfall observed to be. In the case of Batley Waterworks the difference is nearly 60 per cent.

The highest rainfall on a gathering ground appears to be the Harcden gathering ground of Preston Waterworks, namely, 73·33. The Langden gathering ground of the same waterworks is 71·75. The rainfall at Preston is 35·86. The lowest rainfall is found on the Coldwell gathering ground (Nelson Corporation Waterworks), namely, 30 inches.

**Rainfall previous to date of inspection.**

Preceding the *notes on the character of the gathering ground*, a table has in each instance been given of the rainfall for the month previous to the date of inspection of the waterworks, the reason being that the conditions found to exist on the gathering ground were found to be largely dependent on the rainfall. This circumstance has to be borne in mind in consideration of every gathering area, and particularly as to the lead dissolving properties of water derived from it. Thus, I have often found that a stream which supplied a reservoir with a neutral water during dry weather yielded a highly acid water during storm time.

**The importance of taking into account the rainfall.**

To take one or two examples. On June 18, 1895, Thornton Moor catchwater conduit (Bradford Corporation Waterworks) contained a neutral water. Prior to this date there had been very little rain. When the rain came a sample was obtained (July 2), which was said to represent storm water. This sample, however, was also neutral, and it possessed no plumbo-solvent ability. As this sample did not appear to be in reality storm water, another was obtained on July 5, 1895. This last sample was discoloured with surface peaty water, and indubitably represented flood water. It was found to be strongly acid, and to be possessed of very considerable plumbo-solvent ability.

On October 3,1894, Mossmoor catchwater conduit (Wakefield Corporation Waterworks) contained very little water, and what water there was was derived chiefly from springs, the surface peaty water being nearly all dried up owing to drought. This water was neutral, but on November 7,1894 (a time coincident with heavy rainfalls), the water was found to be distinctly acid and to be capable of dissolving lead to a very considerable extent.

It is important that the notes on the characters of the gathering grounds and on the conditions found to exist on these gathering grounds be read in relation to the rainfall *previous* to the date of inspection.

**Storm water.**

It will have been noted that in describing the waterworks reference is repeatedly made to the existence (or otherwise) of means for excluding storm water. Where such arrangement exists it may work automatically or be under the control of the foreman of the waterworks. To the latter there is the serious objection that it must often be impossible, in the event of one of those sudden storms which so frequently break over moorland gathering grounds taking place, to get the flood water turned down the storm water course before serious fouling of the water in the reservoir has taken place. Moreover, the best intentioned of foremen may be hampered by instructions of the officials of the waterworks to keep the storage reservoirs plentifully supplied with water, no matter what its quality may be. I would not be understood to imply that wherever I met with liability of storm water to pollute the supply, danger existed in consequence of the ability of such storm water to carry into the supply organic matter of animal origin potentially dangerous (*e.g.*, in regard of enteric fever) to the water consumer. It is right to observe that in most cases the whole of the drainage area is owned by the water authority, or, at least, is subject to some measure of control by the waterworks officials. On many of the gathering areas reported on, the likelihood of danger of the above sort arising seems exceedingly remote.*

**Comparison between "dry weather flow" and "storm" water.**

But fouling of the water with organic matter of vegetable origin, which must needs occur on any gathering ground where storm water is admitted to the supply, is chiefly of importance because such fouling is liable to be associated with acquisition of the properties of acidity and plumbo-solvency by the water.† The importance of this subject will be understood when it is stated that the "dry weather flow" of many moorland water supplies is neutral and free from action on lead, but that the "storm water" in nearly all cases is distinctly acid and possessed of considerable plumbo-solvent ability. As an example of a satisfactory arrangement for excluding storm water from the waterworks, reference may be made to the note on Batley Corporation Waterworks. Also to the case of Oldham Corporation Waterworks, where flood water is excluded from all the reservoirs used for domestic purposes by means of storm water courses.

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* Thus in the case of the Barrow-in-Furness, Keighley, and Oldham Waterworks, among others, their respective corporations own all, or nearly all, the land bordering the reservoirs, and the streams supplying the reservoirs and the watersheds may be considered to be in large measure free from risk of dangerous pollution.

† At the same time it is open to question whether the large amount of vegetable organic matter present in some of these unfiltered moorland water supplies may not, *per se* be prejudicial to health.

In Burnley Corporation Waterworks, on the Cant Clough gathering ground, there is no arrangement for excluding storm water from the waterworks and the whole of the water draining from the gathering ground has to pass through Cant Clough reservoir; in consequence, after a flood the water in the reservoir may be fouled. On the Swinden gathering ground, on the other hand, a watercourse runs along one side of Swinden Reservoir No. 1, and by its means storm water can be excluded from the supply. In Morley Corporation Waterworks on both sides of the storage reservoir are bye-channels, which are continued up to Withen's Clough at the upper end, and which pass down the sides of the embankment, to unite below in the bed of the same stream. They are designed to carry storm and overflow water to compensation. They can also be used to carry away the whole flow of certain of the inlet streams, when they are turbid and discoloured after a storm. In Nelson Corporation Waterworks, on the Coldwell gathering ground, there is an arrangement by means of which the water from all the streams which discharge ordinarily into the reservoir may be turned down a storm water course. In some cases where there is no provision for excluding storm water the water is "treated" before being sent into consumption. For example, Rochdale Corporation Waterworks. Sometimes, although there exist means for excluding storm water, exigencies of providing an adequate supply necessitate the utilisation of some, at all events, of the storm water. For example, in the case of the Blackmoorfoot supply of the Huddersfield Corporation Waterworks there are sluices in connexion with the catch water conduits to turn storm water to compensation. When Blackmoorfoot storage reservoir is low, however, the storm water is allowed to enter, thereby fouling it to a serious extent.

As a single example of the difference between fair weather flow water and storm water, reference may be made to the Oldham Survey. Dowry Beck, on May 16, 1896 (dry weather flow), yielded a neutral water, and one free from plumbo-solvent ability (experiment 7), and on August 3, 1896 (storm water flow) a water strongly acid and possessed of considerable plumbo-solvent ability (experiment 10).

It would, of course, be impracticable to require, in the case of a water supply of moorland origin, that flood water should be excluded under all circumstances and at all times. But it should be recognised that the unregulated admission of flood water is the principal cause of the acid, and therefore objectionable water, which is, in some instances, almost continuously supplied to the consumers. For instance, during summer drought for weeks, possibly for months, a reservoir may be fed with water, small in amount, but neutral and free from plumbo-solvent ability. Meanwhile, the water in the reservoir sinks lower and lower, until possibly there is danger of a water famine in the area supplied. Then a storm comes, and it is to be understood that storms on upland gathering grounds are frequently of almost tropical severity; the consequence is an enormous bulk of water, derived often from the surface drainage of peat, and carrying with it grosser particles of peat, is brought down. If the whole of this storm water, including the first washings of peat, is allowed to pass into the reservoir in order to raise the level of the water as speedily as possible, fouling of the supply, with dangerous results as regards acidity and consequent plumbo-solvent ability, will occur, and may continue for an indefinite time.

**Arrangements for excluding "storm water" from the smaller feeding streams.**

Besides the arrangement for excluding storm water in bulk from the storage reservoirs, many of the moorland gathering grounds have arrangements in connexion with the various subsidiary feeding streams for preventing peaty matters from entering the waterworks. Thus in connexion with Blackburn Corporation Waterworks, at the intake from each tributary stream in the Whitendale Valley there is a collecting pond having a rough stone filter at its upper end, through which all the water passes before reaching the conduit leading to the works Moreover, storm water is prevented from entering these conduits by means of "leap" weirs. These are mechanical contrivances which permit the dry weather flow to drop through an opening leading to the conduit, but which prevent flood water (which usually means acid peaty water) from so entering into the water supply, owing to the great velocity and volume of the storm water carrying it over and beyond the opening leading to the conduit, and so onwards into the stream, to serve as "compensation" water. Another method of excluding peat brought down by moorland streams is illustrated at the Denshaw system of supply of Oldham Corporation Waterworks. Here Dowry Beck, a moorland stream draining a large tract of moorland, is provided with a "wreck lodge" at its lower end, so as to keep back peat and debris from entering Dowry reservoir. It is also to be noted that, with a similar object, the main streams in the Castleshaw system of supply are pitched to the crest of the hill, in order to prevent the denudation of the sides of the valleys. In the case of Wakefield Corporation Waterworks the chief supply to Ringstone reservoir is from Mossmoor Catchwater. This catchwater conduit is nearly five miles in length, and receives along its course the drainage from a very large tract of moorland. Here in certain instances the water draining from the moors is led into a basin so constructed as to keep back the peat. A similar arrangement is used on other gathering grounds in connexion with certain of the large streams and those which contain most peaty water.

On the relations of spring and surface waters.

In the description of the various waterworks attention is repeatedly drawn to the small proportion of spring water present as compared with surface water, and since most of the gathering grounds are moorland in character, it may be added as compared with surface *peaty* water. As examples of waterworks very deficient in spring water may be mentioned Bacup Corporation Waterworks, Halifax Corporation Waterworks (Fly drainage area), Bradford Corporation Waterworks (Thornton Moor supply), Huddersfield Corporation Waterworks (Blackmoorfoot supply), Keighley Corporation Waterworks (Watersheddels supply), Morley Corporation Waterworks, Sheffield Corporation Waterworks (high level supply), Shipley Waterworks, and Wakefield Corporation Waterworks. As examples of waterworks where spring water is more abundant the following may be noted:—Blackburn Corporation Waterworks, Bolton Corporation Waterworks (High Rid supply), Bradford Corporation Waterworks (Stubden supply and Barden supply); Burnley Corporation Waterworks ("Springs" supply), Colne Waterworks (Flass, Barnside, and Bonnie Booth supplies), Leeds Corporation Waterworks, Nelson Corporation Waterworks, Preston Corporation Waterworks, Rochdale Corporation Waterworks (Spring Mill supply), and Sheffield Corporation Waterworks (low level supply). The question of the quality of spring water as compared with surface water, and their relative abundance on moorland gathering grounds, has been considered above. As has been said, the acid neutralising ability of *moorland* spring waters although not great, is fairly uniform in character. On the other hand, the acidity of peaty waters may and does vary within wide limits. The ultimate state of a mixed moorland water depends, then, very largely on the relative proportion of spring and peaty waters, and upon the degree of

Waterworks containing a small proportion of spring water.

Waterworks containing more spring water.

The ultimate state of a mixed moorland water depends on the proportion and degree of acid neutralising ability of the spring water in relation to the quantity and amount of acidity of the surface peaty water.

acid neutralising ability of the former, and the amount of acidity of the latter. Sometimes the beneficial effect of a fairly abundant supply of spring water is "lost" in the bad quality of a comparatively small bulk of peaty water. Again, sometimes the spring water is relatively smal in amount and the peaty water abundant, but the latter may be so slightly peaty in character as not to overcome the acid neutralising ability of the spring water.

Artificial mixture of neutral spring-water with acid peaty water.

The following laboratory experiments upon mixture of neutral spring and acid peaty water may be here cited.

Equal parts of the Wicken springs (1, 2, 3, 4, 5) were mixed together, and this mixed spring water (which was neutral and free from action on lead) was mixed with Higher Swineshaw Reservoir water in equal proportion. The result was that the mixed water was neutral and did not act on lead, whereas the unmixed Higher Swineshaw Reservoir water acted distinctly on lead, and was very appreciably acid. (Table 1.)

Equal parts of "spring" water which did not act on lead, and which was neutral, and Cant Clough Beck (storm water) which was very acid and acted strongly on lead, were mixed together and kept in an unstoppered bottle for three days. When tested the mixed water was found to contain only traces of acid, and to act on lead to a barely appreciable extent.

Equal parts of moss spring water which did not act on lead and was neutral, and Thornton Moor Reservoir water, which was acid and dissolved lead, were mixed together. After standing overnight the mixed water was found to contain merely traces of acid and to have practically no action on lead.

The gradual change of re-action in a moorland stream from an acid to a neutral water as the result of the entrance of a number of subsidiary streams containing neutral spring water was well exemplified in the case of the River Don. The water from the upper reaches, namely, from Grain, Little Grain, and Swinehill Cloughs was decidedly acid in re-action. These streams contained chiefly peaty water and very little spring water. In its course downwards the Don, as the result apparently of the ingress of eight neutral streams containing chiefly spring water, *gradually* changed in re-action from a water distinctly acid to one less acid, and finally, and before reaching Dunford Reservoir, to a water neutral and free from plumbo-solvent ability.

The evidence of the foregoing experiments, as well as field observations, illustrate the importance as regards acidity and plumbo-solvent action of mixing neutral spring water with acid peaty water. Frequently a waterworks supplies a mixture of spring and surface water to all the consumers. The supply in such case will, as regards lead, have at one and the same time the same properties throughout the whole area served by the waterworks, and in many cases the result of the mixing will be a water of uniformly satisfactory quality. But in instances already alluded to, where the mixed water from one valley is sent to one place and the mixed water from another valley to another place, different portions of the distributing area may receive water of quite different character. And at some waterworks, the spring water is intercepted and sent direct to one area, and the peaty water which has accumulated in a storage reservoir to another area.

Example showing that some waterworks supply different places within their area of supply with water of different quality.

In the case of Ashton, Stalybridge, and Dukinfield Waterworks Joint Committee, certain of the towns (or portions of them) supplied suffered to a serious extent from lead poisoning due to water supply. These same towns were being supplied with water of *totally different character* from the water supplied to the areas exempt from lead poisoning. The arrangements on these waterworks are such that almost pure spring water unmixed with peaty water can be and was, at the time of my inspection, supplied direct to certain areas, and that other areas received peaty water almost unmixed with spring water. Briefly stated, part of the total area supplied received a neutral water; here there was no evidence of lead poisoning. The other part received an acid peaty water, and suffered from lead poisoning. The above conditions obtained prior to December 1894. Since then remedial measures have been in operation, namely, "treatment" of the acid peaty water with lime. Coincident with the time when the beneficial effect of the "treatment" showed itself in an improved condition of the water, lead poisoning was no longer complained of.

In the case of Huddersfield Corporation Waterworks, Blackmoorfoot reservoir, which contains much peaty water, has two mains laid from the north and south tunnel entrance. The north main carries the water to Snodley service reservoir, but first unites with the water from Longwood Reservoir, a supply which, it is stated, is derived chiefly from hillside springs. From the service reservoir, water is distributed throughout the town of Huddersfield, and is also taken along the Leeds Road for the supply of Mirfield and Ravensthorpe. The main from the south tunnel entrance at Blackmoorfoot conveys the water to nine villages and also to a portion of Huddersfield. It follows from the above that the water supplied directly from Blackmoorfoot and that supplied indirectly after admixture with Longwood water and storage in Snodley service reservoir are likely to differ the one from the other in some important respects.

In Nelson Corporation Waterworks the *unfiltered* Coldwell water is conveyed through an iron pipe to "Wades" House service reservoir. From this it goes to Nelson being connected with the main from Ogden in the centre of the town, so that Ogden water can, and does, under certain circumstances, reach the service reservoir. The Ogden water, obtained from a different valley, is *filtered*, and, as stated, is connected with the Coldwell supply. How far this arrangement affects the consumers of the water, either at one portion of the town as compared with another, or at different seasons of the year, is not known.

Bradford Corporation Waterworks has two distinct sources of supply, namely, the "high" and "low" level. The former is obtained from the Denholme and Worth Valleys, and supplies the high-level zone of Bradford; and the latter is derived from the Wharfe Valley, and supplies the low levels of the town. These waters differ in a number of respects.

In Oldham Corporation Waterworks the Denshaw supply is stored in Hanging Lees reservoir. From this a portion of the water is conveyed by a main to the higher parts of Oldham. The rest of the water enters Piethorn reservoir and mixes with the water from the Piethorn gathering ground. From thence it is conveyed by another main to Oldham.

Rochdale Corporation Waterworks supplies the town with water from Hamer Pasture, Spring Mill, and Cowm reservoirs. There is a single main in each instance conveying the respective waters to Rochdale. The mains, however, are connected together so that the water from the different systems can be afforded either separately or in conjunction, as circumstance requires.

Sheffield Corporation Waterworks derives its supply from gathering grounds at Redmires (high level supply), and from the upland valleys of the Rivers Rivelin and Locksley (low-level supply). The character of these gathering grounds and the quality of the water are essentially different.

The argument has sometimes been used by the officials of waterworks that the bad quality of the water complained of in a particular area (usually a small one) cannot possibly hold good, since no objection has been lodged against the quality of the water in the chief area (usually a large town) supplied from the same waterworks. Such an argument has been used in the face of the fact that a selective process was actually in operation, the larger area receiving water of good, and the smaller area water of undeniably bad quality.

## SUMMARY OF EVIDENCE OBTAINED AT THE ACTUAL DATES OF SURVEY AS TO THE CONDITION IN RESPECT OF PLUMBO-SOLVENT ABILITY OF UNTREATED WATER DERIVED FROM THE SEVERAL GATHERING GROUNDS VISITED. (*See* Special Notes of detailed Surveys, heading (*b*).)

**Variation in the quality of moorland water, according to the rainfall.**

It must again be insisted upon that the conditions found to exist at a particular date on the gathering grounds by no means necessarily represent the normal or usual state of things. This is especially true as regards the reaction of the water in the streams "feeding" the reservoirs, and to a much less extent as regards the water in the reservoirs themselves. The observations as regards acidity given for each waterworks in Section II. are to be read along with the amount of rainfall on or before the date of survey. Thus, heavy rainfall may exaggerate the normal or usual state of things as regards the acidity of the various waters, whereas "drought" may create a favourable impression which is not borne out by subsequent observation. In many cases the condition of the water in the impounding reservoirs affords a valuable guide as to the average character of water yielded by a waterworks. Whereas the quality of the water in the "feeding" streams affords an indication of how good or the reverse the contributory waters of a particular water supply may be under different conditions of rainfall; the quality of the "stored" water represents the sum of their variations, and shows not only the condition of the mixture of waters at the time of testing, but also the condition in which the water is likely to remain in the future. For, although a reservoir may vary from time to time as regards the quality of its water, it may be stated in general terms that such water, whether acid or neutral, tends to remain in that condition for a considerable period, if not indefinitely.*

**Re-action of reservoir water.**

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* In one case the interval between two testings of the outlet water from a particular reservoir water was about 4½ years, yet the figures as regards acidity and plumbo-solvency were nearly identical. Some stress may be laid on this fact, lest it be too easily assumed that the conditions observed in the past do not hold good at the present time.

The condition of the reservoirs, as regards the reaction of the water contained in them, is shown in the following table:—

### RE-ACTION of the WATER in the RESERVOIRS.

| Re-action. | | | |
|---|---|---|---|
| Neutral. | | Acid. | |
| Reservoir. | Waterworks. | Reservoir. | Waterworks. |
| Laneshaw | Colne. | Thornton Moor | Bradford (high level). |
| Stubden | Bradford (high level). | Upper Barden | Bradford (low level). |
| Lower Barden | Bradford (low level). | Yateholme (trace) | Batley. |
| High Rid | Bolton. | Entwistle (trace) | Bolton. |
| Swinden 1 | Burnley. | Springs | ,, |
| ,, 2 | ,, | Dingle | ,, |
| Heckenhurst | ,, | Cant Clough (trace) | Burnley. |
| Pennington | Barrow-in-Furness | Ringstone | Wakefield. |
| Poaka beck | ,, ,, | Fewston (?) | Leeds. |
| *Ardsley | Wakefield. | Swinsty (?) | ,, |
| Brushes | Ashton, Stalybridge, and Dukinfield. | Withens | Morley. |
| Coldwell | Nelson. | Upper Swineshaw | Ashton, Stalybridge, and Dukinfield. |
| *Hamer | Rochdale. | Lower ,, | ,, ,, |
| Spring Mill | ,, | Brownhouse Wham Cowm. | Rochdale. |
| Upper Rivelin | Sheffield (low level). | Upper Redmires | Sheffield (high level). |
| Lower ,, | ,, ,, | Middle ,, | ,, ,, |
| Strines | ,, ,, | Lower ,, | ,, ,, |
| Dale Dike | ,, ,, | Graincliffe | Shipley. |
| Ogden | ,, ,, | Ogden (trace) | Halifax. |
| Dam flask | ,, ,, | Fly | ,, |
| Ramsden Wood | Halifax. | Upper Dean Head (trace). | ,, |
| Ingbirchworth | Barnsley. | Lower Dean Head (trace). | ,, |
| Upper Longwood | Huddersfield. | Widdop | ,, |
| | | Blackmoorfoot | Huddersfield. |
| | | Watersheddels | Keighley. |
| | | Dunford Bridge | Dewsbury and Heckmondwike. |
| | | Piethorn (? trace) | Oldham. |
| | | Hanging Lees (? trace). | ,, |
| | | Upper Castleshaw | ,, |
| | | Lower ,, | ,, |
| | | New Year's Bridge (? trace). | ,, |
| | | Crook Gate | ,, |
| | | Dowry | ,, |
| | | Sheephouse | Bacup. |

* "Treated" water.

It appears from the above table that, out of 58 reservoirs, 23 were neutral (about 40 per cent.) and 35 acid (about 60 per cent.) These figures are significant, especially when the great capacity of some of the

Moorland reservoirs more often acid than neutral.

reservoirs, the degree of acidity, and the large population supplied with water, are taken into consideration. It must, however, be remembered that the water from the reservoirs is not always sent directly into consumption, it is frequently mixed with other water, or filtered or "treated" in some way, which partly or wholly removes its lead-dissolving properties, and the towns supplied not uncommonly do not store the water in lead cisterns or use lead service pipes.

Amount of acidity.

As regards the amount of acid present in the waters, it may be stated that 11 contained only traces, and the average amount in the remainder (where estimated) was in round numbers nearly 0·5 (in terms of cc. $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 cc. of the water).

Reservoirs containing very acid water.

Of reservoirs yielding high figures as regards acidity, the following may be mentioned:—Ringstone, Upper Swineshaw, Graincliffe, Fly, Blackmoorfoot, Watersheddels, and Sheephouse reservoirs.

Practically, in all cases where the water was found to be neutral, it was also found to be devoid of plumbo-solvent ability. Moreover, when acid, the plumbo-solvency of the water was found to vary with the amount of the acidity.

On an average, and excluding cases where the action was hardly appreciable, the plumbo-solvent ability was 0·85 (in m. grms. of lead in 100 cc. of water after filtration through lead shot).

Re-action of streams "feeding" the reservoir with water.

Passing next to the re-action of the various "feeding" streams (springs, catchwater conduits, rivers, &c.) the subjoined table is of interest. Owing to the large number of tests that were made only those streams are given which are of some importance.

RE-ACTION of some of the STREAMS, RIVERS, SPRINGS, CATCHWATER CONDUITS, &c., on the various GATHERING GROUNDS.

| RE-ACTION. | | | |
|---|---|---|---|
| Neutral. | | Acid. | |
| Streams, &c. | Waterworks. | Streams, &c. | Waterworks. |
| Flass, Barnside, and Boonie Booth Springs. | Colne. | Four peat feeders S.W. side Thornton Moor Reservoir. | Bradford (high level). |
| Laneshaw Brook Catchwater Conduit (Stubden Reservoir). | Bradford (high level). | North Catchwater Conduit (Upper Barden Reservoir). | Bradford (low level). |
| Moss Spring Water | " " | Yethers Gill | " " |
| S. Catchwater Conduit (Upper Barden Reservoir). | Bradford (low level). | Feeder to Well Spring Clough. | Blackburn. |
| Padmore Sike | " " | Stony Clough | " |
| Pitshaw Dike | " " | Cadshaw Brook | Bolton. |
| Kittlety Sike | " " | Mountain Stream to Springs Reservoir. | " |
| Ramsden Clough | Batley. | Cant Clough Beck | Burnley. |
| Brennand River | Blackburn. | Catchwater Conduit to Cant Clough Reservoir. | " |
| Whitendale River | " | Swinden Brook | " |
| Springs to High Rid Reservoir. | Bolton. | Mossmoor Catchwater Conduit to Ringstone Reservoir. Nov. 7th, 1894. | Wakefield. |
| "Springs" Supply | Burnley. | | |
| Rathmoss Beck | Barrow-in-Furness. | Jack Clough | Morley. |
| Poaka Beck | " " | Fletcher's Dyke | " |

| Re-action. | | | |
|---|---|---|---|
| Neutral. | | Acid. | |
| Streams, &c. | Waterworks. | Streams, &c. | Waterworks. |
| Mossmoor Catchwater Conduit to Ringstone Reservoir. Oct. 3rd 1894. | Wakefield. | North and South Catchwater Conduits. | Morley. |
| River Washburn - | Leeds. | Peaty water from Boar flat. | Ashton, Stalybridge, and Dukinfield. |
| Wicken Springs, Springs, west side of Yeoman Hey Reservoir. | Ashton, Stalybridge, and Dukinfield. | Peat drain, west side of Higher Swineshaw Reservoir. | " " |
| Ogden Clough - - | Nelson. | Two small moorland streams and catchwater conduit to Brownhouse Wham Reservoir. | Rochdale. |
| Langden Stream - | Preston. | Cowm Brook - - | " |
| Hareden Brook - - | " | Graincliffe - - | Shipley. |
| Prickshaw Brook - | Rochdale. | Blackdyke - - | " |
| Rivelin Brook - - | Sheffield (low level). | Weecher - - - | " |
| Strines Brook - - | " " | Catchwater drain to Fly Reservoir. | Halifax. |
| Ogden Water - - | " " | Venemous Clough 1 - | Bacup. |
| Broadstone Dyke - | Barnsley. | " " 2 - | " |
| North, Dean Clough, Ponden Kirk, and Ark Hill Conduits. | Keighley. | " " 3 - | " |
| Dearden Clough and Dearden Spring. | Dewsbury and Heckmondwike. | Catchwater conduit to Blackmoorfoot Reservoir. | Huddersfield. |
| Cold Greave Clough - | Oldham. | Various peat feeders to Watersheddels Reservoir. | Keighley. |
| | | Grain, Little Grain, and Swinehill Cloughs. | Dewsbury and Heckmondwike. |
| | | Cudworth Beck - | Oldham. |

It is manifestly impossible to give for any of the waterworks an indication of the proportion (either as regards number or yield of water) existing between the neutral streams and those that were found to be acid.

Extremely acid waters.

Of waters remarkable for the amount of their acidity the following may be mentioned :—

Water from bog hole about 1,450 feet above sea level and near origin of Dowry Beck (Expt. 8, Table 18).
Dowry Beck during heavy flood (Expt. 10, Table 18).
Catchwater conduit to Blackmoorfort reservoir (Expt. 2, Table 13).
Venomous cloughs (Expts. 1 and 2, Table 2).
Catchwater drain to Fly reservoir (Expt. 4, Table 12).
Graincliffe, Weecher and Blackdyke streams (Expts. 1, 2, 3, Table 22).
North and South catchwaters to Withen's reservoir (Expts. 8 and 11, Table 16).
Fletcher's dyke and Deep Slade stream (Expts. 7 and 10, Table 16).
Cant Clough Beck during flood (Expt. 7, Table 9).
Thornton Moor catchwater conduit (Expt. 9, Table 8).
Peat feeders to Thornton Moor reservoir (Expts. 11, 12, and 13, Table 8).

"Inlet" streams frequently more acid than the water in the reservoir.

Speaking in general terms, and in relation to the observed acidity of reservoirs and their "feeders," it may be said that the streams feeding the reservoirs were slightly more acid than the reservoirs themselves. This, of course, might be expected to be the case, since the reservoirs usually are supplied from neutral as well as from acid streams. Further, excluding the results of fermentative changes in the water or bed of the reservoirs due to the presence of peat, storage tends to reduce the initial acidity, so far as may be judged from laboratory experiments.

**Acid re-action of moist peat.**

On nearly all of the gathering grounds the re-action of the moist peat was determined with litmus paper, and an acid re-action was practically always obtained. The litmus paper was pressed against the moist peat with a fragment of heather, or a small stick or stone, or some other object found on the gathering ground, and not with the hand or a finger.

**Examples of waters neutral during dry weather and acid during storms.**

In this relation instances may be given of streams which during dry weather flow when the spring water was relatively at its maximum, and the peaty water at its minimum, were neutral, but when subsequently examined during heavy rainfall, when the peaty water was at its maximum, were acid. Under the first set of conditions either there was no peaty water, or the acidity of the small amount of peaty water was neutralised by the acid-neutralising ability of the spring water; under the latter set of conditions the acidity of the large body of peaty water overcame the acid-neutralising ability, if any, of the spring water.

The large catchwater conduit which supplies most of the water to Thornton Moor Reservoir was neutral on June 18th, 1895. At this time very little peaty water was gaining access to the waterworks. On July 2, 1895, a sample was obtained which was stated to be "storm water." This water was neutral, and indeed bore little or no resemblance to flood water (Expt. 8, Table 8). Still another sample was obtained (July 5), and in this case the water was much discoloured, and appeared indubitably to represent storm water. It was found to be strongly acid, and to dissolve lead to a very considerable extent (Expt. 9, Table 8).

On the south-west side of Thornton Moor reservoir there are a number of iron pipes which lead water draining from very peaty land into the reservoir. No water was draining on June 18th, 1895, from this area, so instructions were given to send samples as soon as the first flood came. The water thus subsequently obtained was found to be highly acid, and it acted strongly on lead (Expts. 10, 11, 12, 13, Table 8).

On May 16th, 1896, a sample of water obtained from Dowry Beck during dry weather flow was neutral and free from action on lead.

On August 3rd, another sample from the same source, but collected during high flood, was strongly acid and possessed of great plumbo-solvent ability (Expts. 7 and 10, Table 18). As illustrating the severity of thunderstorms on moorland gathering grounds, it may be of interest to note that on the above occasion 1 · 52 inches of rain fell in 1¼ hours.

Swinden Brook during dry weather (April 2nd, 1896) contained traces of acid, and had a barely appreciable action on lead. At an earlier date, March 27th, 1896, and during flood the same water was found to possess distinct acidity and plumbo-solvent ability (Expts. 5 and 6, Table 9).

Cant Clough Beck on April 2nd, 1896 (dry weather flow), was only feebly acid, and acted on lead only to an inconsiderable extent. Previously, March 27th, 1896 (flood water), it had been found to be strongly acid and possessed of great plumbo-solvent ability (Expts. 7 and 8, Table 9).

Mossmoor catchwater conduit on October 3rd, 1894, was found to contain neutral water. On the date the peat "feeders" were dried up and only spring water was reaching the waterworks. A sample subsequently obtained (November 7th, 1894), during a flood was decidedly acid, and it acted on lead to a considerable extent (Expt. 5, Table 23).

Withen's Brook on July 10th, 1894 (dry weather flow), was neutral; whereas on August 24th, 1894, when the conditions were altered as regards the rainfall, it was sensibly acid, and it acted appreciably on lead (Expt. 6, Table 16).

Swineshaw Brook on September 12th, 1894 (dry weather flow), was neutral, whereas on November 1st, 1894 (on this date the streams were running fuller), it was acid.

Oaken Clough on the 14th June 1895 and during drought was neutral. Tested subsequently under ordinary conditions of rainfall it was acid.

On July 25th, 1895, and during very heavy rainfall, Blackmoorfoot catchwater conduit contained a very acid water, and one which acted strongly on lead. On April 1st, 1896, and during dry weather flow, the water contained in it was only about one-half as acid, and the plumbo-solvent ability was reduced about two-thirds (Expts. 2 and 5. Table 13).

On September 27th, 1894, nearly all the feeders supplying Watershed-dels Reservoir were neutral, and this notwithstanding the fact that the water in the reservoir was distinctly acid. At this period very little water, other than spring water, was gaining access to the waterworks. On October 28th, 1894, when the feeders contained a large amount of peaty water, all the streams were acid with three exceptions, and these were streams containing chiefly ferruginous spring water.

These results are, perhaps, sufficiently numerous to indicate the importance of considering the antecedent rainfall in relation to the re-action of moorland streams.

It has already been suggested that many gathering grounds rely almost solely for their supply on storm water, and that during drought, and possibly even during ordinary conditions of the rainfall, the level of the water in the storage reservoirs rapidly sinks. In other words, the supply of water neutral and free from action on lead obtained during dry weather is totally inadequate unless supplemented by water collected during heavy rains, which water is usually acid and possessed of plumbo-solvent ability.

## TREATMENT OF WATER ADOPTED AT CERTAIN OF THE WATERWORKS SURVEYED, AND ITS EFFICIENCY IN REMOVING ABILITY TO DISSOLVE LEAD.

**Effect of the different kinds of "treatment" of the waters.**

Passing next to the consideration of the results of "treatment" of acid waters with a view to removing their plumbo-solvent ability, it may be said that, as a general rule, the result of several kinds of "treatment" was very successful. Acid moorland waters are very amenable to treatment in the above sense.

Wakefield Corporation Waterworks treat their water, which, previous to treatment, is strongly acid and possessed of great plumbo-solvent ability, with a solution of sodium carbonate. Five hundred gallons of a strong solution of soda (about 1 lb. per gallon) are mixed with one million gallons of acid water. The result is very satisfactory, as the water after treatment no longer acts on lead, and is slightly more than neutralised. As regards erosion of lead, to be more fully dealt with in a future report, it may be added that while the "untreated" water possesses strong erosive ability, the "treated" water is not only "cured" in this respect, but is placed, as it were, in a state remote from the possession of erosive ability. No other form of "treatment" appears to confer this property on a water in equal degree. Indeed in some cases treatment, if it does not actually confer on a water erosive power, brings it nearer the possession of this quality than it was before treatment. There is another advantage in this method, namely, that the effects are almost instantaneously produced, and do not depend on the length of time the water is left in contact with the neutralising agent.

It is, perhaps, a drawback that the water is not rendered more clear, but rather the reverse, as a result of the treatment. Less soap is, however, required to form a lather after than before treatment.

At Barnsley the water is filtered, but as the water is already neutral, or was so on July 12, 1895, it is unnecessary to say more than that the filtering material is made up of layers of sand, gritstone, and limestone.

At Sheffield the acid water from the high-level gathering ground is treated with lime (about 2 grains to the gallon) in an apparatus which works automatically and thoroughly mixes the lime and water together. The "treated" milky water carrying an excess of lime in suspension is conveyed for a distance of several miles in a channel made for the purpose to Hadfield service reservoirs. The result may be considered satisfactory as the water is changed from an acid plumbo-solvent discoloured water into a neutral water, free from lead dissolving power, and bright and clear in appearance. It is "harder" after treatment, which is probably an advantage on medical grounds, although less suitable for manufacturing purposes.

At Rochdale, on the old works, there are two reservoirs. The Upper Brownhouse Wham reservoir is acid, and the water is treated in the lower reservoir (Hamer pasture) with lime by means of boats, the lime (whiting, about 1 grain to 1 gallon) being thrown with scoops on the surface of the water. The water is thus neutralised, and loses also its plumbo-solvent ability.

On the new works the water is filtered through sand, and enough whiting is added to the water in the filter beds to cover the sand with a thin coating of lime. Here also the results are equally satisfactory.

At Bradford the water from Thornton Moor reservoir, which is acid and dissolves lead, is treated with pure carbonate of lime (about 3 grains to the gallon), and is then filtered through sand and gravel. The water after treatment is neutral, and no longer dissolves lead.

At Morley many of the inlet streams to Withens Clough reservoir have small filter beds of stone and sand covered with limestone and chalk. This arrangement is not as satisfactory in practice as might have been anticipated. The beds become speedily coated with vegetable matter, and cease to counteract the acidity of water passing through them. In order to neutralise the body of water in the reservoir, slaked lime was added by means of rafts. Slaked lime was also added to water in some of the inlet streams. Later soda in solution was added to the water in the supply well. Before "treatment" Morley main water was acid. Sometime after treatment was in operation, a sample was obtained which contained only traces of acid. Later, however, the main water was found to be more acid than the first sample. Possibly the treatment was no longer in operation at this period.

Prior to December 1894 no "treatment" of the acid Swineshaw water (Ashton, Stalybridge, and Dukenfield Waterworks) was in operation. Subsequently the water from Higher Swineshaw, before entering Lower Swineshaw, was treated with whiting (about 1½ grains to the gallon). On September 12, 1894 (*i.e.*, before "treatment"), Lower Swineshaw reservoir was acid. On September 25, 1895 (*i.e.*, after about nine months treatment), it was practically neutral. Swineshaw water supplies the town of Mossley, and water from the mains there was obtained weekly prior to and for a considerable time after treatment was in operation. This water gradually changed from an acid lead dissolving water to a water practically neutral and free from action on lead.

Keighley Corporation Waterworks resort to filtration in the case of the highly acid Watersheddels water. The water is filtered through coke, then through filter beds containing ground sandstone, broken sandstone, and limestone, and finally through beds of polarite. The treatment is on the whole satisfactory, although the filtered water sometimes contains faint traces of acid and acts very faintly on lead. It will be noted that in the filters the limestone, which may be regarded as the chief neutralising agent, is protected from being coated with slimy vegetable matter, as it lies beneath the ground sandstone. Moreover, the grosser particles in the water are removed by preliminary filtration through the coke. The beneficial effect, *quâ* plumbo-solvency, of the ordinary system of filtration through sand and gravel which is adopted at waterworks in order to free the water from organic impurities was also observed at some works. Such filtration was practised on the Bolton, Leeds, and Nelson Waterworks. It may of itself suffice to remove the whole, or at least the greater part, of the lead dissolving properties of the unfiltered water, in those cases in which the acidity of the water before filtration is not very pronounced.

Although the question of "treatment" is complicated by the fact that a water may have its acidity completely removed and yet be left nearer the possession of "erosive ability" than it was prior to treatment, there can be no doubt that there is no difficulty whatsoever in so "treating" a water as completely to remove its power of *dissolving* lead. Moreover, experiments carried out in the laboratory show that a water which has had its power of dissolving lead removed, and which has been changed from an acid to a neutral water by "treatment" does not, however long it be kept, revert to its original acid state, but remains permanently neutral and free from plumbo-solvent ability.

Which of the various forms of treatment adopted may be termed the best is open to question. I incline, however, to the belief that ordinary sand-filtration, with the addition of some neutralising material (*e.g.*, a thin coating of lime on the surface of the sand with limestone underneath the sand) to the filter and the subsequent addition of a *trace* of sodium carbonate to the neutral filtered water, is the best method. Here filtration* would serve the double purpose of removing impurities from the water and rendering it neutral and free from plumbo-solvent ability. The sodium carbonate would further place the water in a condition remote from the possession of erosive ability. Laboratory experiments, at all events, tend to show that this treatment is the most efficacious.

Each case must, of course, be judged on its own merits, and attention paid not only to the convenience of manufacturers, who raise great objections to any process which hardens the water, but also to the health of the inhabitants. Many medical men are very firmly of opinion that unless moorland waters are "hardened" by means of lime, the health of children suffers to a considerable extent. It may be added that moorland waters will only take up a very small proportion of carbonate of lime, and although slightly hardened by this treatment they still remain very "soft" waters. It will be noted that in a large number of cases the "hardness" of the various waters was determined. It will also be observed that of two waters, the "hardest" was frequently the most acid. So that, while it is true that "soft" waters frequently act on lead and are acid, and "hard" waters seldom possess these qualities, it cannot, of course, be said that the "softer" a water is the greater will its acidity and plumbo-solvent power be found to be.

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* Some authorities, however, object to filtration as removing the vegetable matter which might otherwise form a protective coating in the pipes.

## DIAGRAMS ILLUSTRATING THE CHEMICAL RESULTS OBTAIN FROM THE ABOVE SURVEYS.

**Records showing that neutral waters are free from solvent action on lead, that acid waters are possessed of plumbo-solvent ability, and that there is a decided parallelism between the amount of acidity and the degree of plumbo-solvent action.**

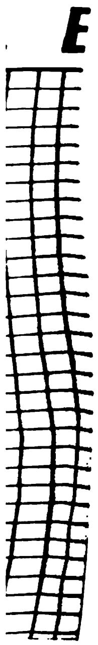
To illustrate the fact, abundantly confirmed in the cou the surveys, that *neutral waters are free from solvent act lead, and acid waters possessed of plumbo-solvent ability* extent dependent chiefly on the amount of acid, diagram B ha constructed. This diagram shows that 65 samples of water neutral and free from action on lead; 29 waters were slightl and dissolved traces of lead; and 77 were distinctly acid and appreciably on lead. As regards the latter, the diagram shows clearly that the greater the acidity, the greater is the action o likely to be. Here the acidity (red line) is arranged from the l up to the highest amount of observed acidity, and the plumbo-s ability (black line) of the *corresponding* sample of water is given will be noted that the relation between the two is well marked, bu the greater the amount of acidity the more widely does the cur plumbo-solvency rise above the curve of acidity. That is to say, o scale adopted it is apparent that the red and black lines run clo together where the waters are only slightly acid, but that when waters are distinctly acid then the curve of plumbo-solvency rises abo the curve of acidity to a considerable extent.

In diagram C the different amounts of acidity of all the acid moorla waters are arranged in red columns, beginning from the lowest apprecia amount and working up to the highest quantity of acid. The plumbo solvent ability of the *corresponding* samples of water is shown by blac columns, and where a number of different samples were examined, a containing an equal amount of acid, then the *mean plumbo-solven ability* is given. The close relation existing between the amount o acid and degree of plumbo-solvency is clearly visible.

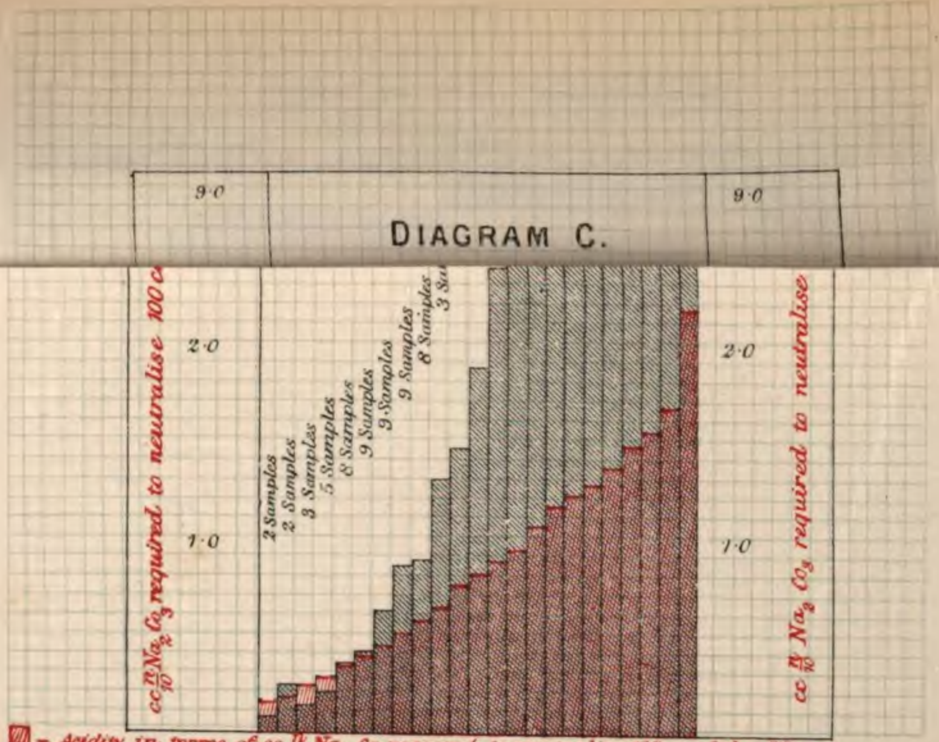
In diagram D the percentage variation above and below the mean as regards the acidity and plumbo-solvency of corresponding samples of water is given. On two occasions the acidity was above the mean whe the plumbo-solvency was below, and on one occasion the plumbo-solvency was above the mean when the acidity was less than the average. In all other cases when the acidity was above the average, so also was the plumbo-solvent ability, and when the acidity was below the mean the plumbo-solvency fell likewise. On the scale adopted, the percentage deviation from the mean as regards plumbo-solvency was on an average about twice as great as the percentage deviation from the mean in the case of the acidity. The diagram indicates very clearly that not only is there a parallelism between the acidity and plumbo-solvent ability of a water (*i.e.*, that a rise or fall above or below the mean as regards the acidity is nearly always coincident with a rise or fall above or below the mean as regards the plumbo-solvent ability), but also that the percentage deviation in each case shows a decided parallelism, allowance being made for the fact that on the scale adopted the plumbo-solvent ability is about twice as great as the acidity on an average.

**Record showing that the spring waters were neutral and free from action on lead, and the peaty waters were acid and possessed of plumbo-solvent ability.**

To illustrate the fact that neutral waters chiefly correspond to spring water, and the acid waters to peaty water, diagram E has been constructed. In this diagram it is shown that the *spring waters were neutral* and *free from plumbo-solvent action*, and that the *peaty waters were acid and possessed of ability to dissolve lead.* Not all the waters are here given, but only those which appeared to be typical of moorland spring waters, and moorland peaty waters. Thus many examples of "mixed" waters are not included.


E

# DIAGRAM C.



▨ = Acidity in terms of $cc\ \frac{n}{10} Na_2\ Co_3$ required to neutralise 100 cc of the Water.
▧ = Plumbo-solvency. mgrms of lead in 100 cc of Water after filtration through lead shot.
Each square represents 0·1 $cc\ \frac{n}{10} Na_2\ Co_3$ or 0·1 mgrm of lead as the case may be.

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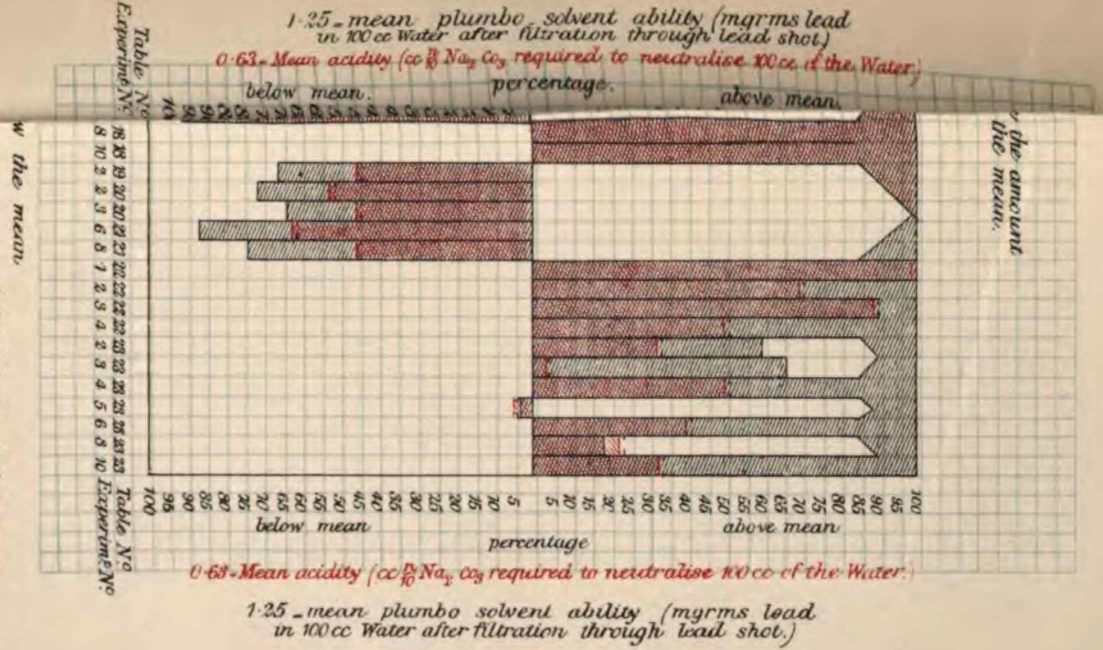

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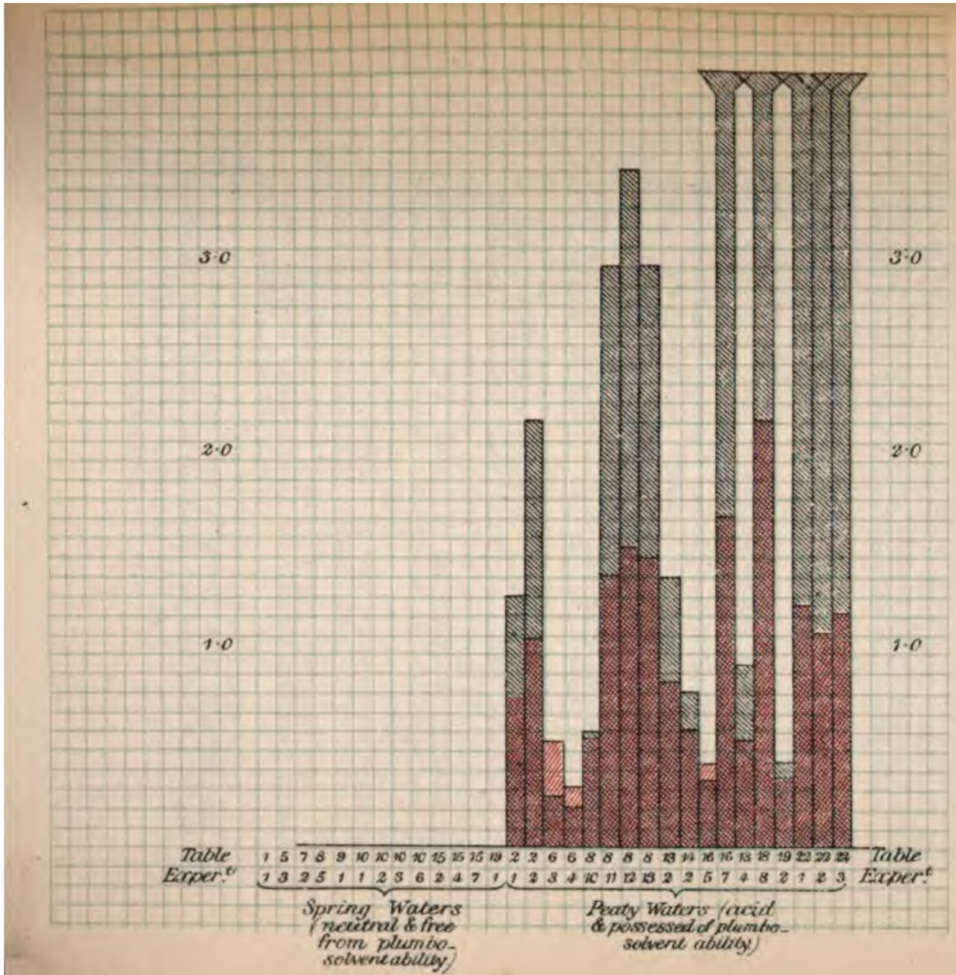

**DIAGRAM E.** showing that spring Waters are neutral & free from solvent action on lead & that peaty Waters are acid and possessed of plumbo-solvent ability.

▨ Black hatching = mgrms of Lead in 100 cc of the Water after filtration through lead shot.

▨ = Red hatching = cc $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 cc of the Water.

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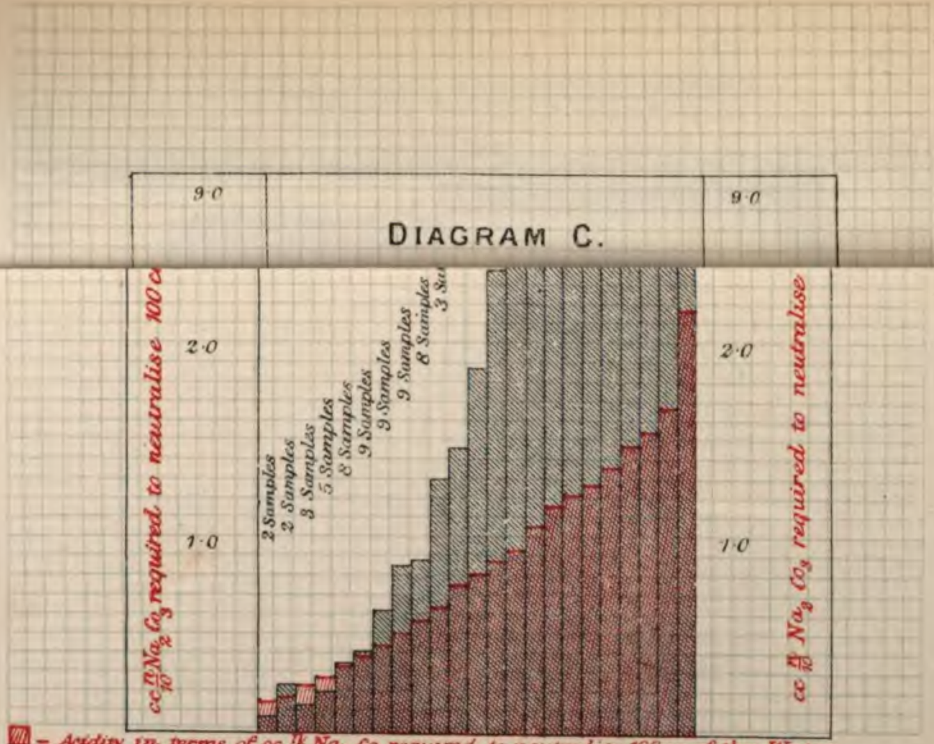
# DIAGRAM C.



▨ = *Acidity in terms of cc $\frac{n}{10}$ $Na_2CO_3$ required to neutralise 100 cc of the Water.*

▩ = *Plumbo-solvency. mgrms of lead in 100 cc of Water after filtration through lead shot.*

*Each square represents 0·1 cc $\frac{n}{10}$ $Na_2CO_3$ or 0·1 mgrm of lead as the case may be.*

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6. The degree of plumbo-solvency of a water is chiefly governed by the amount of its acidity.
7. Moorland spring water is neutral and often possessed of slight acid-neutralising ability. In virtue of this property spring water is commonly capable of neutralising a certain proportion of acid peaty water.
8. Neutral water does not dissolve lead to any appreciable extent.
9. Moorland waters, as received into storage or service reservoirs, usually contain a mixture in variable amount of acid peaty water and neutral spring water. The re-action of the "mixed" water at any given time is determined by the relative amount of peaty water, and the degree of its acidity on the one hand, and by the relative amount of spring water, and the degree of its acid neutralising ability on the other.
10. Rain water is usually neutral, but on some gathering grounds it is slightly acid. Such acidity, however, is quite insufficient to account for the acidity of moorland waters.
11. Water draining from rock rich in iron pyrites may be acid and act on lead. This, however, is seemingly not a common cause of acidity of moorland waters.
12. During dry weather, and especially at the end of a period of dry weather, the water in moorland streams is almost invariably neutral and free from plumbo-solvent ability.
13. During dry weather the water in moorland streams consists chiefly of spring water: during wet weather the water is chiefly surface water draining from peaty soil.
14. During storms the water in moorland streams is usually very acid and acts strongly on lead. Especially is this the case when the wet weather succeeds a period of drought, as then the streams contain the "first washings" of the peat.
15. On most moorland gathering grounds there are areas (particularly on the higher and flatter portions of the gathering grounds) where the rain stagnates in peaty, boggy, and marshy places. Such water has always been found to be acid in re-action.
16. On many gathering grounds a layer of impervious marl underlies the beds of peat. This prevents the escape of the rain in a downward direction, and so the water is "held" in the peat, or escapes only by slow lateral percolation. Thus the peat is always moist, and each successive rainfall washes out of the peat substances formed during the more or less prolonged contact of the water with the peat, rendering the water considerably acid.
17. The "dry weather flow" on most moorland gathering grounds is very small, and is usually quite inadequate to meet the requirements of the town or towns supplied with water.
18. In such cases, during a period of drought, the water in the compounding reservoirs sinks rapidly to a very low level.
19. When heavy rain comes after drought, millions of gallons of acid peaty water are frequently allowed to enter the waterworks. Indeed the storage reservoirs are constructed for this very purpose, namely, to store for future consumption a vast bulk of "storm" water, the ordinary flow of the streams being far too small to keep the reservoirs at their proper level.
20. Thus it not unfrequently happens that, during dry weather, a reservoir water is strongly acid, while all or nearly all the "inlet" streams contain neutral water. In storm time, however, these streams contain not only acid water, but the water in them is usually more acid than the reservoir water itself.

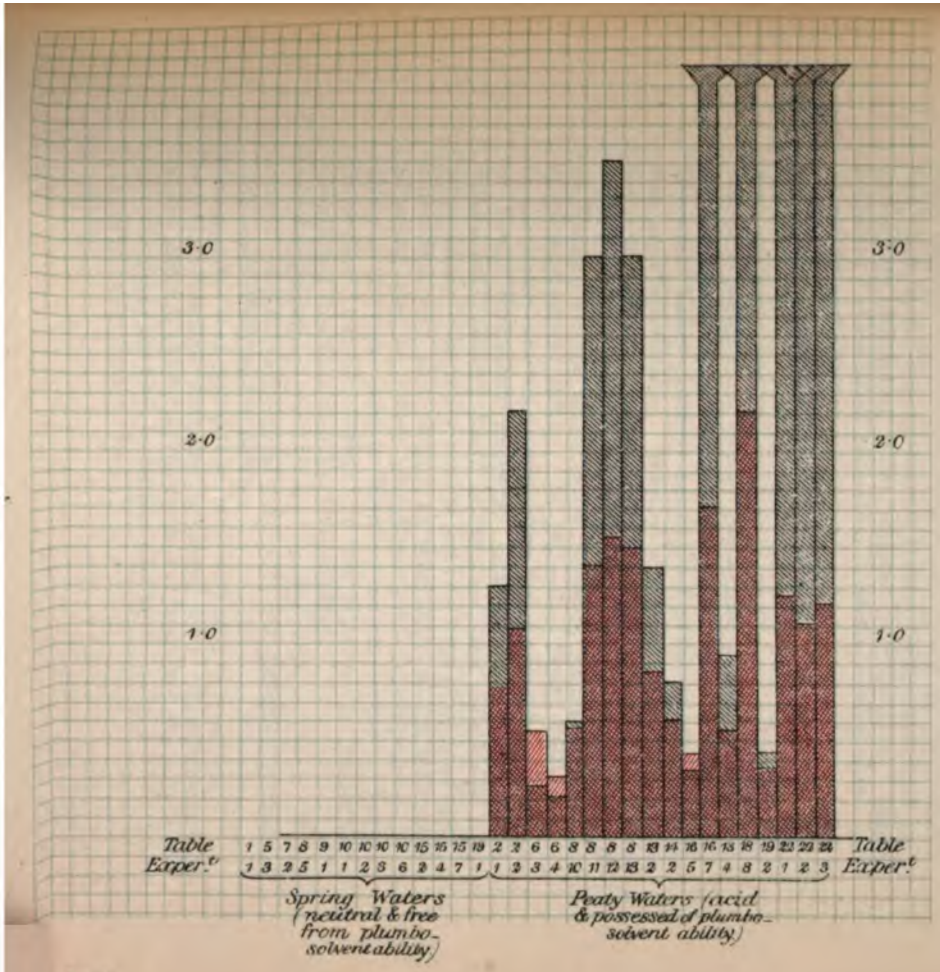

**DIAGRAM E.** showing that spring Waters are neutral & free from solvent action on lead & that peaty Waters are acid and possessed of plumbo-solvent ability.

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waters, to acquire plumbo-solvent ability. Study of this sort affords the most satisfactory means of determining how best to apply the remedy, or combination of remedies, needed in the particular instance. In the case of proposed new waterworks, this inquiry indicates the necessity of a careful survey of the physical characters of the gathering grounds, as well as of ascertaining the proportion of spring water to surface water at different times of the year and under different conditions of rainfall, and of testing the quality of the spring water and its power of neutralising acid, and the quality of the surface water, especially during wet weather and sudden storms following a period of drought.

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